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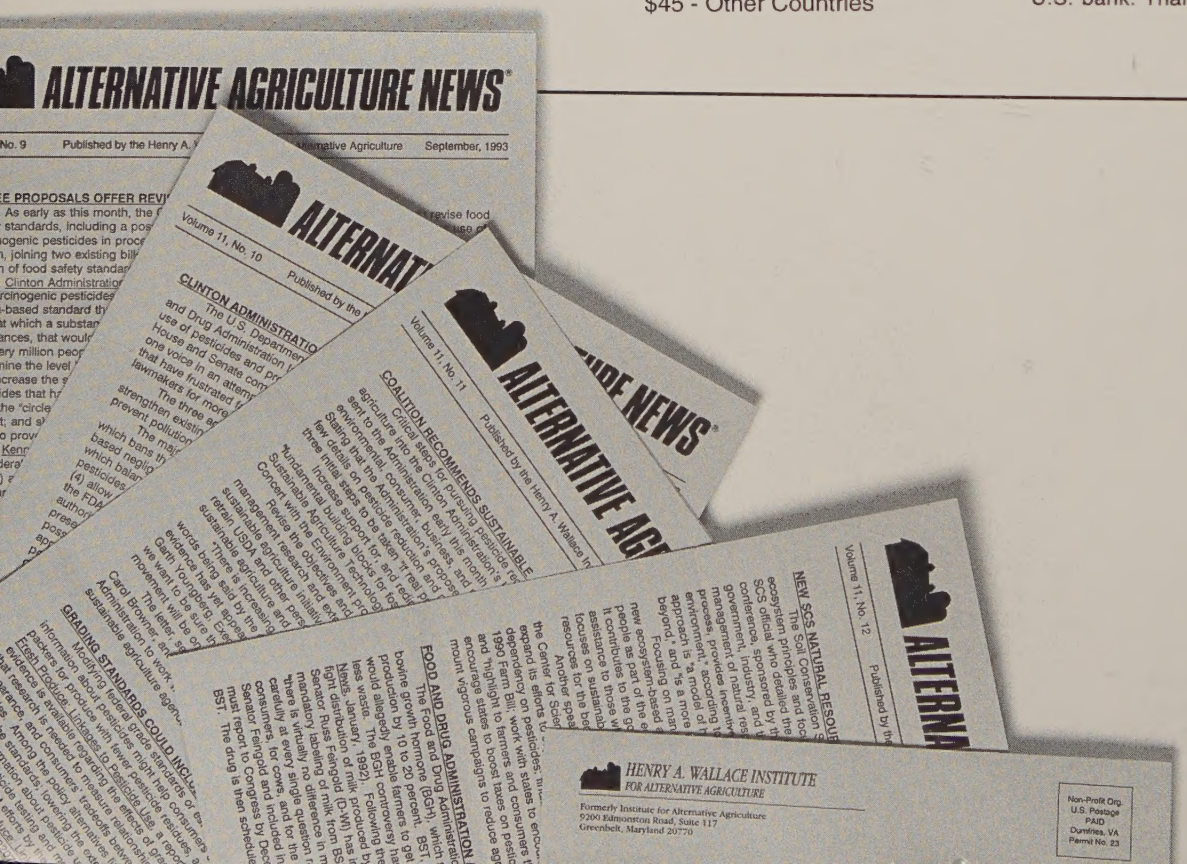

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The Institute is governed by a grass roots Board of Directors, which includes several commercial-scale organic farmers, and maintains a small professional staff. It is supported by memberships and donations and grants from foundations, corporations, and individuals.

Cover Photo

The cover photo shows Barred Plymouth Rock chickens free-ranging in a potato-intercropped apple orchard at Kellogg Biological Station, Michigan State University. Photo provided by M. Sean Clark, Department of Entomology, Michigan State University, East Lansing, MI.

The Wisconsin integrated cropping systems trial: Combining agroecology with production agronomy

Joshua L. Posner, Michael D. Casler, and Jon O. Baldock

Abstract. *Two large-scale (25 ha) trials were initiated in 1989 in Wisconsin to compare six alternative production systems regarding productivity, profitability, and environmental impact. The project was designed and is managed by a coalition of farmers, extension agents and research personnel. Deliberations between production-oriented and ecologically oriented team members resulted in a factorial design, with two enterprise types (cash grain and forage-livestock) and three levels of biological complexity. Statistical methods have been used to identify the most efficient plot size, plot shape, and block shape, and the optimal procedures for sampling soil characteristics. A uniformity year was allowed before initiation of the trial, and the start was staggered. We defined treatments as production strategies rather than a specific set of inputs, which led to a more flexible plot management program.*

Key words: agroecological index, homogeneity year, long-term research, sampling statistics

In response to the growing public concern about the environmental impact of American agriculture, cropping system trials have been recently established in Wisconsin and other states in the Midwest. Historically, long-term trials have focused on a few variables. For example, the classic Rothamsted (England, c. 1843), Morrow (Illinois, c. 1876), Sanborn (Missouri, c. 1888), Magruder (Oklahoma, c. 1892), and Old Rotation (Alabama, c. 1896) plots were initiated primarily to address the question of maintaining soil fertility and crop yield. The options under study were crop rotations and organic and inorganic fertilizers (Jenkinson, 1991; Mitchell et al., 1991). In the 1970s, trials were established to study the long-term effect of alternative tillage systems on crop yields and soil variables (Dick et al., 1991). In addition, several other trials in the Midwest have been established to study the "rotation effect" on crop yield, in both predominately row-crop-based (Sahs and Lesoing, 1985; Peterson and Varval 1989a,b,c; Crookston et al., 1991; Meese et al., 1991) and sod-based systems (Baldock et al., 1981; Hesterman et al., 1986).

Many of these recent rotation trials are attempting to characterize the long-term sustainability of alternative production strategies. Concomitant with this expanded focus has been a growing effort in the land-grant colleges to widen the research circle to include farmers, consumers and educators (Stevenson and Klemme, 1992). Meeting these broader environmental and political objectives places new challenges on conventional experimental statistics, requiring careful reflection on treatment and experimental design. In this article we explain the statistical underpinnings of the Wisconsin Integrated Cropping Systems Trial (WICST) and their implications for how we conducted the study. We hope that this will promote a dialogue on initiating long-term trials aimed at sustainability issues in agriculture.

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Background

Setting the objectives

The initial research group, consisting of plant, animal and soil science researchers, intended to establish a trial focusing on the environmental impacts of alternative production strategies. However, at the first meeting it became obvious that more than physical and biological science would be necessary. The project, therefore, was expanded to include producers, extension agents, social scientists, and agronomists from an organic farming research group (the Michael Fields Agricultural Institute).

This expansion led to several changes. While producers were interested in the environmental impacts of different production strategies, their main interest was the annual profit margins expected with alternative systems. Also, they were concerned that reduced-input systems could increase weed pressure and decrease soil fertility. To address these concerns, the group realized it had to define the treatments in both economic and biological terms, and to monitor the early changes carefully, long before an equilibrium was reached. Also, the producers were primarily interested in comparing entire systems or strategies, rather than just yields of single crops as a function of different levels of inputs. This emphasis on the economic and agronomic consequences of

the transition to different production strategies and on whole systems analysis had important implications for the choice of treatments and the experimental design.

Duration of the trial

The team envisioned that collecting information on the costs of transition would be completed after one or two cycles through each rotation. If alternative production systems are less profitable than conventional systems after four to eight years, they are unlikely to be adopted. On the other hand, it is more difficult to argue when a steady-state crop rotation environment would be reached in each rotation. As suggested by Cady (1991), the trial should continue until the rotation effects are fully expressed and production approaches long-term yields. Biologically, the time required to reach steady-state conditions is open to question, but it can be tested with specific hypotheses. Discussions of the statistical analysis will show how this will be achieved. We anticipate that the trial will run at least 12 years.

Trial location

During this preliminary phase, the team decided to focus the project on Major Land Resource Area 95B in Southeastern Wisconsin and Northern Illinois (U.S. Dept. of Agric., 1981), mainly because it is close to the university. Within this land unit the major gradients for production agriculture are the depth of silt loam cap over glacial till and the level of internal drainage. The team chose to work at two sites, the Arlington Research Station (ARS), which is on a deep, well-drained Typic argiudoll, and the Lakeland Agricultural Complex (LAC) at the Walworth County Farm, which is on a shallow, somewhat poorly drained Aquic argiudoll. When farming began in this area in the 1840s, the main cropping system was continuous wheat. From shortly after the Civil War until the 1960s, dairying predominated, but since the 1960s, farmers have been abandoning dairying. Now, nearly two-thirds of the farms are in cash grain or vegetable production. The two sites selected for the long-term trial have been managed predominantly as dairy farms during the past 30 years, using a rotation of alfalfa (*Medicago sativa* L.) and corn (*Zea mays* L.), with manure applications.

Choice of Systems

The first design issue that the steering committee had to address was the disagreement between members who were mainly concerned, respectively, with production and ecological considerations. The former wanted to limit the comparisons to a narrow range of economically competitive alternative systems. The latter wanted to expand the trial focus to the full range of alternative land use systems, ranging from native grasslands and forests to intensively cropped fields. The committee compromised on the agroecological hypothesis that with increasing biological complexity, a production system could be maintained with less reliance on external inputs (Altieri, 1985; Harwood, 1985). However, the range of systems was restricted to options available to farmers.

The second disagreement concerned the definition of realistic rotation options. According to the 1987 *Census of Agriculture* (U.S. Dept. of Commerce, 1989), approximately 40% of the farms in southeastern Wisconsin have dairy cows. These farms, with their forage-based rotations and access to manure, have different crop production options from those that primarily produce cash grains. We, therefore, decided to develop rotations for the two enterprise types separately.

Combining these two factors resulted in a nested factorial design: enterprise type (cash grain vs forage-based) and production strategy (high, medium or low reliance on external inputs or, correspondingly, low, medium, and high biological complexity). Statistical hypothesis testing will mainly be on differences among the three input levels within each enterprise type, and secondarily on the comparison between enterprise types. (Note that the designations *high*, *medium* and *low* are meaningful only within the same enterprise type; we do not regard the two high-input systems as a class that can be compared to the two medium-input or two low-input systems.) The members agreed that "production strategies" refers to entire systems, so that the meaningful comparisons are between full rotations. Therefore, we will not compare individual crops within rotations or specific production techniques within years, such as mechanical vs. chemical weed control or nitrogen from green manure vs. anhydrous ammonia. The crop rotations selected are diagrammed in Fig. 1. The pasture system plots were composed of a mixture of red clover (*Trifolium pratense* L.), timothy (*Phleum pratense* L.), smooth bromegrass (*Bromus inermis* Leyss), and orchardgrass (*Dactylis glomerata* L.).

More difficult than defining the two enterprise types was quantifying the biological complexity of the rotations. Although reduced costs for purchased inputs are a common proxy for biological sustainability, the team wanted to develop a broader agroecological variable. Eight system descriptors were selected. Using average yields and previously published data, we calculated values for each rotation (WICST, 1993), summarized in Table 1. With the first five criteria, high values were considered desirable from an agroecological viewpoint. It seemed logical that high values of productivity, dry matter recycling, energy output/input ratio, nitrogen fixation and biodiversity were positive attributes of crop production systems. Conversely, low energy subsidies, low C-factor values for crop cover in the Universal Soil Loss Equation and infrequent tillage also would be positive attributes of cropping systems. The data in each row was then standardized as $t=(X_i - M)/s$, where X_i = the value for the i^{th} rotation, M = the mean over the six rotations, and s = the standard deviation. Composite t-values for each rotation were computed as $t_h - t_l$, where t_h = the sum of the t-values for the five criteria for which high values are desirable, and t_l = the sum of the three for which low values are desirable. This composite t-value was then converted into an agroecological index by adding 5.44 to each value so that continuous corn (R_1) would equal 1 (Table 1, row 10). From R_1 to R_6 the range in agroecological index values is from 1 to 7.7 Not surprisingly, the index values are higher for the forage-based systems (R_4 to R_6) and lower for the cash grain systems (R_1 to R_3). However, variable costs per hectare are higher for the cash grain systems (Table 1, row 11).

We also made several key practical decisions about the definitions of the treatments at this time.

1. Typically, agronomic research keeps the treatments constant over the duration of the experiment. However, because of the complexity of the cropping systems, we decided that some aspects of the treatments would be fixed while others could change.

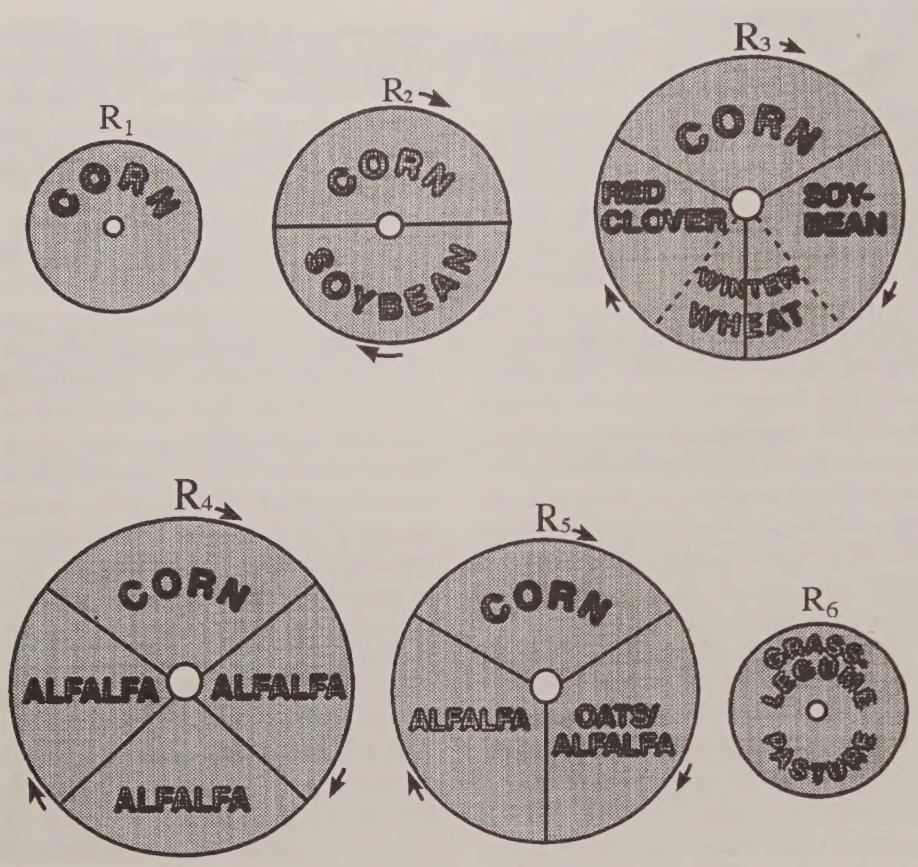

Figure 1. Schematic drawing of the rotations in the Wisconsin Integrated Cropping Systems Trial. (Area of each circle is proportional to the length of the rotation.)

The crop rotations (Fig. 1) and the production strategies (high, medium, and low external inputs) were regarded as fixed. The six crop rotations also were fixed because each has a long history in the Upper Midwest, and because the importance of each crop is unlikely to change much during the trial. Also, the general features of input use were regarded as fixed.

However, we regarded many specific inputs as variable because agronomic practices can evolve rapidly with changes in technology, economics, and public opinion and policy. Therefore, we decided to review production practices annually (Frye and Thomas, 1991) and make changes as needed. For example, improved crop varieties should be incorporated as they are developed; fertilizer rates should be adjusted to match soil analyses; types and rates of herbicides should be adjusted as old compounds become outdated or new compounds become available; and tillage systems should be modified as new techniques or equipment are proven to be beneficial. This will help us keep each treatment up to date and adjust it to changing field conditions. However, these changes are made in the context of the particular production strategy. That is, if weed control becomes a problem, then in the low external input systems (R_3 and R_6) more mechanical and cultural control measures would be tried before resorting to herbicides, whereas herbicides would be the first choice in the high external input systems (R_1 and R_4).

2. A potentially more controversial decision was that each plot would be managed as a separate field, so that protocols might vary even within a treatment. Because each treatment is a production system, application of the treatment demands flexibility in solving problems that arise. For example, we would occasionally spot-treat patches of quackgrass or thistle with herbicide rather than spraying all four plots of a treatment uniformly and unnecessarily. Similarly, reseeding of winter-killed areas and cultivation of row crops are done only as needed. Inputs to each plot are charged to that plot only, so that input costs may vary from one plot to another in the same treatment. This practice may increase error variances for input variables but will more accurately reflect true plot-to-plot variation. This decision has increased farmers' confidence in the accuracy of the input and output data.

3. The most difficult system to design was rotational grazing (R_6). Because of the difference in the area required, grazing and crop rotations are rarely included in the same trial. Generally, studies of weight gain on pasture require large amounts of land to allow use of enough animals to deal adequately with variations among animals (Stuedemann and Matches, 1989). Because each of the four pasture plots would be small and could only accommodate a few heifers, four options for controlling error were considered.

- Mob grazing with a large herd to defoliate the pastures rapidly. This approach would only allow us to assess how the grazing strategy affected the plants and soil, but not to measure animal production and economic performance.
- Smaller ruminants, such as sheep. We ruled this out because of the overwhelming economic and environmental importance of dairy cattle within the state and region.
- A single herd of moderate size (10 to 12 heifers) that would rotate among the replicates, grazing fenced paddocks within each plot on a 20 to 25-day rotation. This would allow us to determine weight gains and analyze the economics of the pasture system. However, we could not statistically compare the economics of the pasture system and the other systems each year because the pasture system would be unreplicated.
- The traditional model for a grazing study, but with only two or three young heifers (180 to 220 kg) per plot.

After considerable deliberation, we chose the last option. However, if weight gain varied too much among animals on a plot, or the "herd" behaved strangely with only two or three animals, the third option would be used. In that case, standard errors for comparing economic results of the pasture systems with the other systems could be computed from the treatment × year interaction variances after several years of data collection. The coefficient of variation for seasonal animal weight gain was only 6.7% at LAC in 1992, and 7.8% at LAC and 8.7% at ARS in 1993, suggesting that the last option may be

Table 1. Cropping systems agroecological descriptors and index.

Criterion	R_1 C-C-C-C	R_2 Sb-C	R_3 Sb-W/RC-C	R_4 A-A-A-C	R_5 O/A-A-C	R_6 Grazing
High values desirable						
1. Aboveground productivity[1] (dry matter, Mg ha^{-1})	18	14	11	12	11	9
2. Percent dry matter recycled[2]	55	58	53	59	67	35
3. Energy output/input ratio[3]	6.0	6.9	12.6	13.7	18.2	104
4. N fixation[4] (kg ha^{-1} yr^{-1})	0	85	105	145	125	65
5. Biodiversity index[5]	1	2	4	2	3	5
Low values desirable						
6. Energy subsidy[6] (Mcal ha^{-1})	5,850	4,420	1,880	2,930	2,000	320
7. Crop cover factor[7]	0.15	0.15	0.11	0.07	0. 06	0.02
8. Frequency of disturbance[8]	1	.5	.67	.5	.67	0
Composite t-value	–4.44	–1.50	–0.84	1.60	1.92	3.25
Agroecological index	1	2.94	3.60	6.04	6.36	7.69
Estimated variable costs ($ ha^{-1} yr^{-1})	346	257	124	272	111	40

[1] **Above ground productivity**: Based on expected yields and typical harvest indices.
[2] **% dry matter recycled**: Calculated using the harvest index and considering manure additions as dry matter returned to the field. In Rotation 6 the off-take was meat. It was estimated that 35% of dry matter intake was not digestible and was returned to the field as manure.
[3] **Energy output/input ratio**: The ratio of energy output from the system to energy input to the system, excluding solar and human energy (Pimentel, 1980).
[4] **Nitrogen fixation**: Estimated amount of nitrogen that is fixed during the legume phases of the rotation, divided by the number of years in that rotation.
[5] **Biodiversity index**: The number of species grown each year on the farm.
[6] **Energy subsidy**: The sum of all inputs, converted into energy equivalents (Pimentel, 1980). Energy inputs in animal production are not included in rotations 4, 5 and 6.
[7] **Crop cover factor**: The rotation crop cover factor (C) in the Universal Soil Loss Equation.
[8] **Frequency of disturbance**: The proportion of years when tillage takes place.

reasonable (Undersander and Posner, 1993; Paine and Undersander, 1994).

Experimental Design

The homogeneity year

Brandt's dictum (as quoted in Cady, 1991) simply stated is that in long-term rotation experiments, each crop of each rotation must be grown each year, with the treatments randomized. Accepting the producers' desire for the work to be conducted on large plots and the researchers' concern about sampling procedures, we decided to conduct a homogeneity trial. The uniformity year had three objectives:

- to block the trial based on corn yield variability;
- to test how effectively the blocking plan removed variation in baseline variables other than corn yield;
- to identify an adequate sampling procedure for baseline variables.

Blocking the trial

At each site an area of approximately 25 ha was set aside for the trial. Corn was planted on the entire field in 1989. We measured yields with a weigh wagon during every third pass with the 6-row combine in pre-marked 25.8 m lengths. Yields from the harvest strips were also considered representative of the bulked strips on either side, resulting in a unit yield plot of 25.8 m × 13.8 m. There were 625 plots at ARS and 665 at LAC. Fortunately, 1989 had a typical growing season, and mean corn yield was 8000 kg/ha at ARS and 9550 kg/ha at LAC.

Harvest units were aggregated into "plots" with sizes ranging from 0.038 ha (1 unit) to 0.301 ha (8 units in a 1×8, 2×4, 4×2, or 8×1 configuration). Aggregated plots for each size and shape were then grouped into 12-plot blocks of various shapes (1×12, 2×6, 3×4, 4×3, 6×2, and 12×1), assuming a 12-treatment randomized complete block experiment. Twelve "treatments" were used because it allowed for convenient aggregation for each plot size and was very close to the eventual number of treatments in the long term study, namely 14 rotation-phase combinations. We aggregated harvest units and "plots" by manipulating row and column codes in the computer data file. One-way analysis of variance was computed on the plot mean corn yields for each plot size, plot shape, and block shape combination. The error variance (plots within blocks) was used to estimate the $LSD_{.05}$ (Steel and Torrie, 1980), considering a future trial with from 3 to 6 replicates. Plot shape did not affect the magnitude of calculated $LSD_{.05}$ values, but block shape had an effect and was used to design the blocking pattern; the 1×12 option was chosen.

Doubling the number of replicates reduced the $LSD_{.05}$ by 30% (Table 2). Although more replicates would markedly increase costs, the farmer-inspired focus on the transition period meant that we would need good precision from the start. Doubling the plot size, which would be cheaper than doubling the number of replicates, also was effective, and reduced $LSD_{.05}$ by 14 to 32%. As expected, the largest reductions in $LSD_{.05}$, which came from increasing plot size, were for the smallest plots. Because we wanted to use farm-scale machinery, we decided that plots needed to be long, with adequate alleyways for maneuvering (15 to 20

Table 2. The effect of plot area and number of replicates (r) on $LSD_{.05}$ of corn yield during the uniformity year, 1989.

Plot size (ha)	$LSD_{.05}$ (kg/ha) r=3	r=4	r=5	r=6
Arlington Research Station (ARS)				
0.038	447.1	386.1	345.5	315.0
0.075	345.5	299.7	266.7	243.8
0.113	312.4	269.3	241.3	221.0
0.151	279.4	243.9	218.5	198.1
0.226	266.7	231.1	205.8	188.0
0.301	241.3	210.8	188.0	170.2
Lakeland Agricultural Complex (LAC)				
0.038	561.4	487.7	434.4	396.3
0.075	383.6	330.2	297.2	271.8
0.113	337.8	292.2	261.6	238.8
0.151	—	—	—	—
0.226	271.8	233.7	210.8	190.5
0.301	—	—	—	—

m wide). As a result, we determined that the project could afford a maximum of four replicates, and chose a randomized complete block design. The available land area with four replicates would allow a plot size of 0.30 ha at each location, which was expected to be as efficient as a plot size of 0.19 ha with five replicates or 0.13 ha with six replicates. Results from the uniformity year predicted that $LSD_{.05}$ values for corn yield would be between 200 and 300 kg/ha. During the first three production years of the experiment, $LSD_{.05}$ for corn yield at the two locations has ranged from 100 to 400 kg/ha.

Effectiveness of the blocking plan on other variables

At ARS, besides the yield study, we established a 55-m×27-m soil sampling grid. In spring 1989, ten soil samples (0 to 15 cm depth) were taken within a 5-m radius of each grid point, for both soil fertility and weed seed measurements. We then classified sampling points according to block and plot number in the newly established field map. The soil variables were subjected to analysis of variance using the randomized complete block model and the new randomization plan. Analysis of variance revealed large and significant ($p<0.01$) differences among block means for several variables, four of which are shown in Table 3 (row 3). Although we blocked exclusively according to patterns of variation in uniformity-year corn yield, blocking also removed a large portion of the variation for these variables. Furthermore, the lack of significant treatment effects (rows 4, 5, and 6) shows that the randomization of treatments to plots was effective in eliminating potential bias to individual treatments. Therefore, future treatment comparisons for these variables will not be confounded by variation in initial levels.

Sampling protocol

There were three overriding considerations in establishing a sampling protocol for each variable: 1) the range in means expected as the systems approached an equilibrium; 2) the inherent variability in the measurements; 3) the effect of that variability on the statistically detectable difference between means.

Table 4 (row 1) shows the means for the weed seed and soil P and K levels taken during the uniformity year. Considering that the area had been in an alfalfa-corn rotation for several years and had heavy applications of manure, the grass and broadleaf numbers were regarded as average to somewhat high for typical forage rotations (J. Doll, UW-Extension Weed Scientist, private communication, January 1990). An initial hypothesis was that the continuous corn with herbicide and one cultivation (R_1) would ultimately have the lowest weed seed load, because it is easy to kill grass weeds in corn with herbicides. In contrast, we expected that the 3-year low-input rotation (R_3), with two years of row crops, would have the highest weed seed load, because it relied on mechanical cultivation. We estimated that there would be a range of 5,000 grass weed seeds/m^2 between the "best" and "worst" rotations. Broadleaf weeds were more prevalent at the site and are more difficult to control. We estimated that the maximum range of broadleaf weed seeds would increase to 11,000 seeds/m^2 between R_1 and R_3 (Table 4, row 2).

We did a similar analysis of soil P and K levels in the plow layer. Because starter fertilizer was used in the continuous corn plots (R_1), we estimated that the high levels of P and K would be maintained. On the other hand, in the low-input rotation (R_3), nutrient removal would not be offset by either fertilizer or manure. Assuming average yields, P and K levels were estimated to

Table 3. Block means and significance levels for block and treatment effects for 1989 uniformity-year data at ARS superimposed upon the long-term experimental design of the WICST.

		Weed seeds[1] ($10^3/m^2$)		Soil[1] (ppm)	
		Grass	Broadleaf	P	K
Block means					
High		2.11	9.37	120	288
Low		0.46	3.20	79	225
Significance levels					
Blocks		<0.01	<0.01	<0.01	<0.01
Treatment effects	(df)				
Enterprise type	1	0.13	0.59	0.12	0.08
Strategy within enterprise	4	0.30	0.64	0.40	0.19
Phase within strategy	8	0.67	0.31	0.18	0.12

[1] 0–15 cm soil sampling depth.

Table 4. Means and sampling statistics for four variables measured during the uniformity year at ARS in 1989.

	Weed seeds[1] ($10^3/m^2$)		Soil[1] (ppm)	
	Grass	Broadleaf	P	K
Mean	1.5	6.8	103	265
Predicted maximum range[2]	5.0	11.0	90	220
Experimental error (s_e^2)	0.4	5.5	81	1782
Sampling error (s_s^2)	4.0	31.0	974	5881
Ratio s_s^2/s_e^2	10.1	5.6	12.1	3.3
Minimum detectable treatment difference[3]	1.3 (25%)	4.7 (43%)	18 (20%)	85 (39%)

[1] 0–15 cm soil sampling depth.
[2] Range expected among treatment means after 12–16 years of rotation.
[3] Based on p=0.05, power=80%, replicates=4, and an infinite number of samples per plot. Values in parentheses are detection levels expressed as a percentage of the expected range.

drop to equilibrium levels of 10 ppm and 45 ppm, respectively, within 15 years (E. Schulte, UW-Extension Fertility Specialist, private communication, January 1990). Yields would also drop, because optimum soil test levels are considered to be 20 ppm for available P and 100 ppm for exchangeable K (Kelling et al., 1991). These calculations lead to a maximum expected range of 90 ppm P and 220 ppm K between R_1 and R_3 (Table 4, row 2).

To determine the variability in the measurements, we analyzed them according to a nested sampling model; the three sources of variation were blocks, plots within blocks, and samples within plots. Variance components for the experimental error (plots within blocks) and sampling error (samples within plots) were estimated for each variable (Table 4, rows 3 and 4). The large ratios of sampling to experimental error (Table 4, row 5) mean that the sampling units were very heterogeneous in 1989. This demanded careful attention in selecting enough samples to reduce the variance, but not so many that the costs would be prohibitive.

Fig. 2 shows how the number of samples per plot affects the detectable difference between means for several variables using a power of 0.8. (Power is the probability that the hypothesis test correctly detects real differences among treatment means.) As the number of samples increases, the detectable differences approach a lower limit controlled largely by the number of replicates, which is fixed, and the variance components, which are subject to considerable sampling error. Row 6 of Table 4 shows the minimum detectable differences based on the 1989 variance components. For the weed seed sampling we selected a sample size of six, each consisting of five cores, which is expected to result in detectable differences between means equal to 41% of the expected range for grasses and 60% for broadleaf weeds. Although those levels are 15 to 20% above the minimum possible (with an infinite number of samples), they provide a good chance of detecting treatment differences, if they exist, at a reasonable cost.

Designing the soil sampling plan was made more difficult by questions about whether the variation in soil test levels from banding starter fertilizer is random or systematic, and the effectiveness of field mixing and subsampling for the composite samples. Consequently, we relied on studies of mixing and subsampling soil composites in the laboratory (Schulte, private communication, March 1993), of banded P application (showing that P concentration decreases exponentially as the distance from the application band increases) (Kitchen et al., 1990), and of optimal grid sampling schemes for 0.9-m×0.9-m sampling squares (de Gaubeke, 1969). Our plan is to take three composite samples per plot. Each composite consists of six cores taken in two groups of three, with the three cores taken at right angles to the direction of the corn rows and spaced 20 cm apart. This plan should be at least as precise as taking three samples at random, which provided a detectable treatment difference of 46% of the expected range for P and 57% for K (Fig. 2).

Results from spring 1992 (Table 5) show that weed seed numbers are dropping under continuous corn and increasing in the mechanically weeded plots (R_3), as we expected. The differences in both broadleaf and grass weed seed numbers between these two rotations already is significant. Also as expected, the continuous corn rotation has approximately maintained P levels while R_3 is showing a drawdown of these nutrients (Table 5). Not surprisingly, the difference in soil test P and K values between rotations is not yet significant.

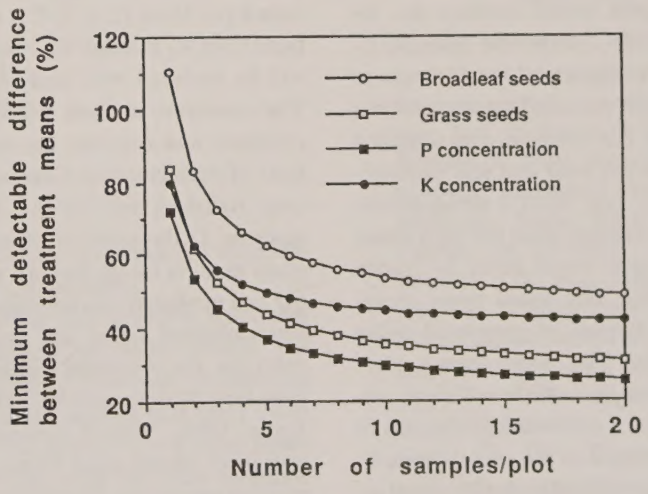

Figure 2. Effect of increasing the number of samples per plot on the minimum detectable difference between any pair of treatment means, expressed as a percentage of the long-term expected range among treatment means. Fixed parameters are p = 0.05, power = 0.8, and replicates (r) = 4. Computation based on rearranging formula in Steel and Torrie (1980, p. 119): $d = (t_{0.025,99} + t_{0.2,99})[2(s_s^2 + ns_e^2)/rn]^{1/2}$

Table 5. Comparison of R_1 and R_3 with respect to weed seed bank and soil fertility evolution from 1989 to 1992.

	Weed seed bank[1] ($10^3/m^2$)				Soil fertility[2] (0–15 cm)			
	Grass		Broadleaf		Available P		Exchangeable K	
	1989	1992	1989	1992	1989	1992	1989	1992
R_1: C-C-C-C	1958	288	7378	1928	105	93	257	219
R_3: Sb-W/RC-C	1608	1442	6430	8177	105	69	236	189
$LSD_{.05}$	NS	668	NS	1905	NS	NS	NS	NS

[1] Soil sample made up of 30 cores, 0–15 cm depth, 0.92 cm diameter. Total number of emerged plants after three wetting cycles in the greenhouse.
[2] Composite of 5 cores, 0–15 cm depth, 0.92 cm diameter.
Sources: Doll et al., 1993; Iragavarapu et al. 1993.

We will sample plots each year for weed seeds and soil minerals. To minimize expenses, plots in R_1 through R_5 will be sampled only after a corn crop. This reduces the number of samples, but still provides a determination within each cycle after the "test crop" phase of each rotation. We will sample the pasture rotation every fourth year because it is expected to change very slowly, if at all.

Using a staggered start

If a rotation study is begun with all phases of the rotation planted the first year of the study, data on the entire system is available immediately. However, with that start-up method each plot will develop a different crop history; e.g., in a corn-soybean rotation one plot would develop the sequence C-Sb-C-Sb . . . and the other Sb-C-Sb-C . . . . Consequently, it would be more difficult to obtain unbiased results for some measurements. For example, the sampling plans call for weed seed and soil measurement following corn. With a simultaneous start, the data collected after the corn phase from the two plots would never be exactly comparable since they would never represent the same number of completed cycles in the rotation. The simultaneous start method also penalizes the lower input systems that require a previous legume crop to help supply nitrogen to the cereal phase in the rotation. The more statistically sound alternative is to use a staggered start, in which one phase is chosen as the starting point and one more plot is brought into the rotation each year until a complete cycle is obtained (Fig. 3). To ensure a uniform plot history, a filler crop (corn in this study) is grown on the plots until they are worked into the rotation.

Superimposed on Fig. 3 are shaded ovals and rectangles that highlight two complementary approaches to the statistical analysis of the experiment. The ovals enclose the combination of plots that would be used in the transition analysis of the trial data. For example, after 1996 we will have 7 years of data on R_1, six completed rotations from R_2, and five completed rotations from the three-phase R_3. For economic, environmental, and production variables, we first will compute means for all observations within each shaded oval. (An observation is defined here as the value of a variable, measured on a single phase of a rotation in a single year.) These data will provide 34 means per block (7, 6, 5, 4, 5, and 7 observations from R_1 through R_6, respectively), and will be analyzed with analyses of variance. The transition analysis will compare crop rotations and examine the transitional effects of each rotation. Comparisons among crop rotations will involve two kinds of analysis: 1) the contrast of enterprise type (cash grain vs forage-based); and 2) the linear and nonlinear relationships between the agroecological index and measured variables for the rotations within each enterprise type (Carmer and Seif, 1963; Steel and Torrie, 1980). We will compute short-term transition effects using orthogonal polynomials to investigate the presence of linear or nonlinear trends in measurement variables. In the longer term, these data may require more sophisticated nonlinear methods.

While the transition analysis will be interesting for short-term responses, it will be most useful in the long run. For example, following the 2004 growing season (15 years of data) rotations 2 through 5 will have completed two to four replications (because of the staggered start) of 7, 5, 3, and 5 cycles, respectively. For each rotation, this will allow us to examine detailed long-term responses of economic, environmental, and production variables, using straightforward statistical procedures. For rotations 2 through 5, the repetitions will allow computation of means over two to four phases, moderating year-to-year variation in these comparisons. For rotations 1 and 6, this will not be possible because years and cycles are completely confounded. However, using 15 observations should help to establish temporal trends even with some year-to-year weather variation.

The rectangles, on the other hand, represent a whole-farm analysis approach to the same data. Here we analyze farm-wide output, income, or environmental impact variables, assuming an entire farm is in one of the six rotations. The emphasis in this analysis will be the effect of years, rotations, and the rotation × year interaction. This analysis, for example, will focus attention on the risk involved in the alternative systems. It will address the long term year-to-year stability of each rotation and allow comparisons among rotations, for both long-term mean performance and stability.

The data from the first 4 years of the trial have been analyzed using the whole-farm model. Gross annual rotation margins are shown for the cash grain rotations from Arlington (Fig. 4a) and Lakeland (Fig. 4b). Gross margin is gross revenue minus variable costs, and represents the returns to the farm's unpaid fixed resources (labor, management, capital, and land). Although the corn-soybean rotation clearly was the most profitable in 1991 and 1992, it is interesting that the three-phase rotation with soybeans-wheat-corn was statistically equivalent to continuous corn in 1992 and 1993 at both locations. At the end of 1993, and every year after that, all the plots are in their proper rotation position, and the whole farm can be analyzed for all six rotations.

Conclusions

Widening the circle of collaborators to include producers and extension agents has modified the direction of the Wisconsin

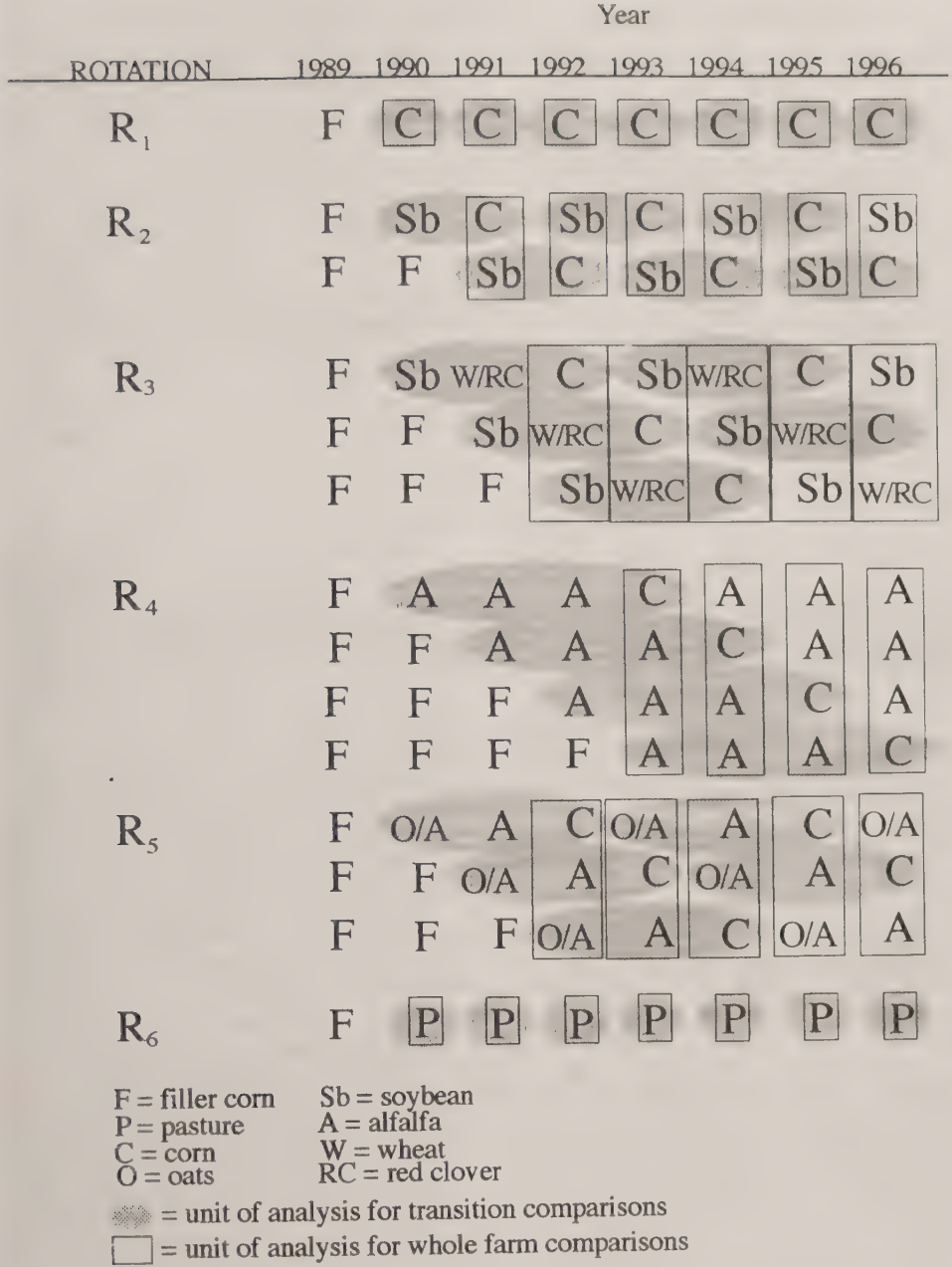
Year
ROTATION
1989 1990 1991 1992 1993 1994 1995 1996
R1
F C C C C C C C
R2
F Sb C Sb C Sb C Sb
F F Sb C Sb C Sb C
R3
F Sb W/RC C Sb W/RC C Sb
F F Sb W/RC C Sb W/RC C
F F F Sb W/RC C Sb W/RC
R4
F A A A C A A A
F F A A A C A A
F F F A A A C A
F F F F A A A C
R5
F O/A A C O/A A C O/A
F F O/A A C O/A A C
F F F O/A A C O/A A
R6
F P P P P P P P
F = filler corn
P = pasture
C = corn
O = oats
Sb = soybean
A = alfalfa
W = wheat
RC = red clover
= unit of analysis for transition comparisons
= unit of analysis for whole farm comparisons

Figure 3. Staggered start for the WICST.

Integrated Cropping Systems Trial. It grew from primarily studying the environmental impact of alternative production systems, to developing two learning centers with a focus on agroecology and production agriculture. Producers were mainly interested in the early years of the rotations and their effects on farm economics, weed pressure and changes in soil fertility. The extension agents had the same interests, but also saw the trial as an outdoor classroom for their education programs. Both groups emphasized a systems analysis of the data. Their input markedly changed the treatment design and threw into question the common assumptions of researchers.

To address this new situation, while still developing statistically valid results, the team made several decisions. Traditional agronomic wisdom dictates that fixed treatments should be applied every year. However, in this trial, only the crop rotations and the production strategies were regarded as fixed, with the specific inputs regarded as adjustable. It was agreed that the agronomic inputs would be reviewed annually and updated as necessary, and that plots would be treated as separate fields so they would receive inputs only as needed. Both modifications have resulted in more realistic cropping systems and have underscored the definition of cropping systems as production strategies, not production recipes.

With the decision to have large plots, we decided to delay the start of the trial for a year and to conduct a uniformity experiment. The variability in corn yield data was then used to block the crop rotation trial. We also used results from intensive sampling for weed seeds and for soil P and K to develop statistically valid sampling schemes for these environmental variables. The tradeoff between the need for good data during the early years (the problem of heterogeneity) and the cost of replications led us to set up four blocks per site with plots of approximately 0.3 ha. The hard work of conducting a uniformity year and the willingness of the participants to intensively sample the area strengthened producers' confidence in the quality of the data being generated by the coalition of farmers, extension personnel, and researchers.

To date, developing the Cropping Systems Trial has been a learning process for all involved. The inclusion of farmers during the initial design raised several challenging problems to the research agronomists. However, as the objectives have become more encompassing, we have been able to design statistical tests to meet our needs.

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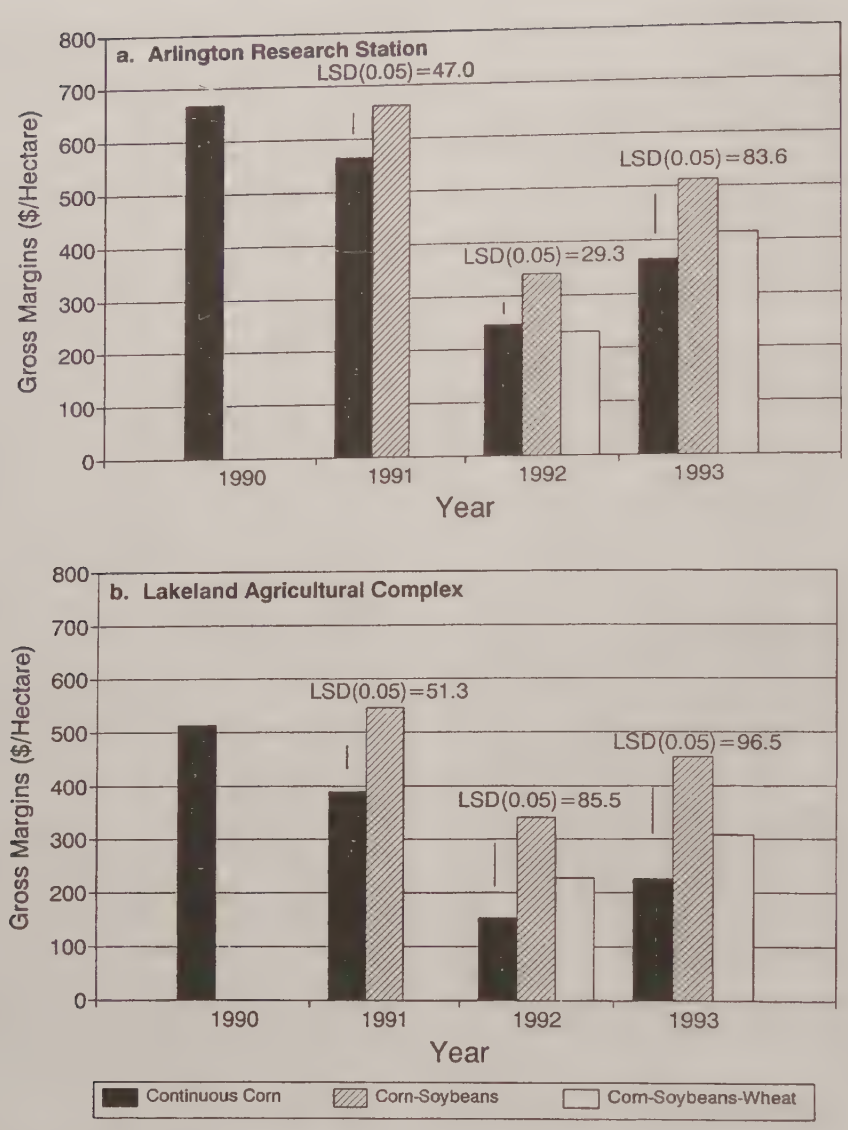

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RESOURCES

"Micro-Irrigation of Trees and Vines," 155 pages, (WMS publication #94-01) is $15 from Tania Heta, UC Cooperative Extension office, Department of Land, Air and Water Resources, 113 Veihmeyer Hall, University of California, Davis, CA 95616; (916) 752-1130.

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"Resource Guide to Aquaculture Information," "Rural Studies Bibliography," "Directory of Rural Studies Scholars and Educators," and **"Biotechnology and Sustainable Agriculture: A Bibliography"** are available by sending a self-addressed, stamped envelope to National Agricultural Library, USDA, 10301 Baltimore Blvd., Beltsville, MD 20705-2351; aquaculture phone/e-mail, (301) 504-5558, aic@nalusda.gov; rural studies, (301) 504-5372, ric@nalusda.gov; biotechnology, (301) 504-5947, biotech@nalusda.gov

"Rural Communities: Legacy & Change," a video series about 17 rural U.S. regions, is available from Marvin Bowman, Ohio University Telecommunications Center, (614) 593-4955; e-mail tcom@ohiou.edu; or call PBS, 1-800-LEARNER.

"Liquid Manure Application Systems: Design, Management, and Environmental Assessment," NRAES-79, is $25 from Northeast Regional Agricultural Engineering Service, Cooperative Extension, 152 Riley-Robb Hall, Ithaca, N.Y. 14853-5701; (607) 255-7654.

"Alternative Approaches to On-Farm Research and Technology Exchange," a project of North Central SARE Region and Agriculture in Concert with the Environment, is $10 from Center for Sustainable Agricultural Systems, University of Nebraska-Lincoln, Lincoln, NE 68583-0949; (402) 472-3022; e-mail: csas004@unlvm.unl.edu

"Maintaining the Public Benefits of Private Forests Through Targeted Tax Options" is $5 plus $1.60 shipping from American Forests, P.O. Box 2000, Washington, D.C. 20013; or call Robbie Ferguson, (202) 667-3300 ext. 200.

"Two Steps Back, One Step Forward: Cuba's National Policy for Alternative Agriculture" is available from International Institute for Environment and Development, 3 Endsleigh Street, London WC1H ODD, UK; phone 071-388-2117.

University of Minnesota has established a new graduate minor program in Sustainable Agriculture Systems; for information, contact Mary Brakke, Program Coordinator, c/o Minnesota Institute for Sustainable Agriculture, 411 Borlaug Hall, University of Minnesota, St. Paul, MN 55108-1013; (612) 624-1222; e-mail, brakk001@maroon.tc.umn.edu

"Practices and Performance of California's Organically Grown Crops" is a series of studies on almonds, apples, cotton, wine grapes, rice, processing tomatoes, and walnuts, $1 each; contact Department of Agricultural Economics, Attn: Linda Fugitt, University of California, Davis, CA 95616; (916) 752-9376.

"Animal Agriculture: Information on Waste Management and Water Quality Issues" is free from the U.S. General Accounting Office, P.O. Box 6015, Gaithersburg, MD 20884-6015; (202) 512-6000; fax, (301) 258-4066.

"The Conservation Reserve: A Survey of Research and Interest Groups" is $12 from Council for Agricultural Science and Technology, 4420 West Lincoln Way, Ames, IA 50014-3447; (515) 292-2125.

"Impacts of the Delaney Clause on California Agriculture" is free from California Department of Food and Agriculture, Office of Pesticide Consultation and Analysis, 1220 N St., Sacramento, CA 95814; (916) 654-0462.

"Sustainable Agriculture Decision Cases," written and video materials, $25, and **"Sustainability: The Quiet Revolution,"** a 45-minute video, $45, are available from Minnesota Extension Service Distribution Center, 20 Coffey Hall, 1420 Eckles Ave., St. Paul, MN 55108-6069; (612) 625-8713.

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Farmers' markets and the local community: Bridging the formal and informal economy

T.A. Lyson, G.W. Gillespie, Jr., and D. Hilchey

Abstract. *Farmers' markets are important but inadequately studied contributors to local economies. They allow individual entrepreneurs and their families to contribute to the economic life of local communities by providing goods and services that are not readily available through formal, mass markets, and they bring producers and consumers together to solidify bonds of local identity and solidarity. Using data collected from 115 farmers' market vendors in three regions of New York in 1993, we examined the characteristics and operations of three categories of vendors: full-time growers, part-time growers, and non-grower artisans and craftspeople. Drawing on theories of mass production and mass markets, we show how farmers' markets represent intermediate social structures that bridge the formal and informal sectors of the economy.*

Key words: direct marketing, community development

Introduction: The Role of Farmers' Markets

Farmers' markets are intermediate social structures bridging the formal and informal sectors of the economy. They provide product outlets both for farmers and for rural artisans, craftspeople and home-based manufacturers. Although some farmers' markets restrict the products that can be sold, all offer agricultural goods. Many also offer handicrafts, food products, and other products manufactured in households and on farms. Farmers' markets not only give members of the public direct contact with producers, but also provide alternatives to the uniform and standardized mass produced, mass marketed products that dominate the U.S. economy. For both producers and consumers, farmers' markets occupy social spaces in which formal market transactions are conditioned by local community norms, values and culture.

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Before the advent of the modern supermarket, farmers' markets in the United States daily offered consumers fresh produce and on-farm processed foods directly from producers. Most cities had at least one farmers' market. In large cities, farmers' markets often catered to the particular tastes and needs of residents living near these markets (National Municipal League, 1915; West, 1927).

The number of farmers' markets in the United States began to decline in the 1920s, when modern supermarkets first appeared (Markin, 1963). The industrial cities of the manufacturing belt were growing rapidly and automobile transportation was forging links between rural residences and urban workplaces. As the urban population expanded, the connection between food production and consumption was dissolving. Markin (1963, p. 7) notes that "as heads of households and breadwinners took up the lunch pail and moved to the factory, these families began to realize that there were economies to be attained by giving up home gardening and replacing it with retail store shopping."

Today, mass manufacturing and marketing dominate the American economy (Piore and Sabel, 1984). In the food sector, for example, six large multinational corporations accounted for 46% of the total of $221 billion in retail food and beverage sales in the United States in 1992 (Standard and Poors, 1994). Such corporations provide abundant quantities of relatively inexpensive, standardized goods. They do less well, however, in meeting the many community-specific preferences for nonstandard or specialized goods that cannot be mass produced and mass marketed economically. Meeting the needs of niche or segmented markets simply is not profitable for large producers.

Although farmers' markets decreased substantially after 1940, they never disappeared entirely. They offered a convenient outlet for producers who could not or did not develop linkages to the mass market. They filled an important niche for consumers who valued quality and variety over quantity and uniformity or who wished to support local agriculture.

Today the U.S. is witnessing their rebirth. Between 1965 and 1994 the number of farmers' markets in New York State expanded from 6 to 174 (Sullebarger, 1983; Johnson and Bragg, 1994). Similar increases have been noted in other northeastern states (Jenkins, 1994). The United States Department of Agriculture identified 1,755 farmers' markets nationwide at the end of 1993 (Johnson and Bragg, 1994).

More generally, while large, mass production manufacturers have played a major role in shaping consumption patterns across the country, smaller producers have always had considerable latitude in meeting the demand for specialized goods and customized products. In fact, some economic observers see modern forms of craft production gaining prominence in advanced industrial societies and displacing mass production as

the dominant industrial model. According to these theorists, the post-industrial landscape will not be controlled by large multinational producers. Rather, smaller, craft-based manufacturers organized around local production districts will again come to the forefront (Piore and Sabel, 1984; Perrow, 1993).

According to Perrow (1993, pp.397–398), small firm networks "represent the possibility of a massive disengorgement from the big organizations, a spewing out of functions over delimited spaces where they can be picked up by small independent organizations. Small organizations are linked together by a sense of a community of fate, rather than a link based on employees sharing the goals of the owners and top executives of a big organization." Today, modern local craft districts produce electronics and textiles in the Emilia-Romagna region of Italy (also known as the "Third Italy") (Piore and Sabel, 1984), machine tools in Pennsylvania (Shafer, 1989; Sabel, 1993), and wine in New York (Lifton, 1989).

When mass markets cannot meet all demands for specialized, nonstandardized food and agricultural products, farmers' markets may play increasingly important roles. They reduce the costs and risks for smaller-scale, informally organized, or household-based producers to enter the market. Thus, they facilitate entrepreneurship and contribute to local economic development. Structurally, farmers' markets are part of an economic configuration that is more akin in scale and organization to the model of development based on production districts and small firm networks than to the dominant model based on mass production and marketing.

We have identified three groups of producers for whom farmers' markets represent important arenas for exchange. For some traditional, full-time growers, farmers' markets can account for a large portion or even most of their farm sales. Over the past 40 years, the number of marketing alternatives in the processing sector for farmers in the Middle Atlantic region (New York, New Jersey, Pennsylvania) has decreased considerably. In 1965 there were 6,345 food processors in the region (U.S. Dept. of Commerce, 1967). Of these, 5,230 (82.5%) employed fewer than 50 workers. By 1991 the number of food processors in the region had dwindled to 2,921, of which 2,231 (75.8%) employed fewer than 50 workers (U.S. Dept. of Commerce, 1993).

Small food processors tend to connect with small producers (Lyson and Geisler, 1992; DuPuis, 1993). Not surprisingly, as the number of food processors decreased, especially small processors, so did the number of small family-size farms (Lyson and Gillespie, in press).

Therefore, for the remaining family farmers with small operations, the growth of farmers' markets in the Northeast may represent an economic lifeline. Farmers' markets also offer promise for new entrants to farming who can market their products effectively. In 1992, 9.3% of full-time farmers in New York, 15.5% in New Jersey and 10.2% in Pennsylvania sold products directly to consumers (U.S. Dept. of Commerce, 1994).

Part-time growers and market gardeners represent another segment of the agricultural community who can be aided by the reemergence of farmers' markets. Farmers' markets let them sell their products directly to consumers and can supplement other direct sales outlets, such as roadside stands, pick-your-own operations, and direct mail marketing. In 1992, 12.9% of the part-time farmers in New York, 17.5% in New Jersey and 11.7% in Pennsylvania sold directly to consumers (U.S. Dept. of Commerce, 1994).

Finally, the growth of farmers' markets in the Northeast has been fueled by artisans, craftspeople, and other entrepreneurs. Many farmers' markets are outlets for local handicrafts and for homemade and farm-based manufactured products. For some vendors, selling at a farmers' market is the first step on the path toward beginning a formal business (Kent, 1992); for others it is a low risk, low investment way to supplement existing income. In both instances, however, farmers' markets are a bridge between households, as informally organized production units, and local (community) marketplaces.

As a social structure linking the formal and informal economies, farmers' markets are organizationally flexible. They accommodate diverse personal motivations, products, and organizational strategies. They allow producers to enter and leave easily, while enduring as an organization.

In this article, we report findings from an exploratory study of farmers' market vendors in New York State. We start with the three groups discussed above: 1) full-time growers, those whose farms or greenhouses are the main sources of their livelihood; 2) part-time growers and market gardeners who have significant off-farm income; and 3) craftspeople, artisans, and small-scale food processors and retailers. Based on the responses to our survey, our observations of several dozen farmers' markets in the Northeast, and the literature, we think these three groups account for almost all vendors in the region.

Study Population and Data Collection

The population of farmers' markets was specified using a directory compiled by the New York State Department of Agriculture and Markets. We selected nine farmers' markets, three in each of three types of rural regions: stable rural areas; old industrial labor markets undergoing restructuring; and urbanizing communities. These three regions represent the general social and economic conditions of most rural communities throughout the Northeastern U.S. (Gillespie et al., 1994). We omitted large urban centers (e.g., the New York City Greenmarket) because our primary objective was understanding how farmers' markets foster entrepreneurship and stimulate community development in nonmetropolitan areas.

To be included in the study, a market needed to have been in existence for at least two years, have a mix of vendors (e.g., growers, craftspeople, and food businesses), and have more than just a few vendors to survey. Among markets meeting these criteria, we sought a mix of organizational structures, such as both public and private sponsorship. We interviewed the managers of the selected markets and then recruited them to help with the data collection.

We collected data from vendors between April and October of 1993 via a self-administered questionnaire. To ensure anonymity, batches of numbered surveys with addressed and stamped return envelopes were sent to each market manager. The market manager assigned a survey number to each vendor and then distributed the questionnaires and return envelopes. The completed questionnaires were mailed directly to us. The managers sent reminder cards to each vendor two weeks after the initial distribution. If we did not receive a questionnaire

after two months, we contacted nonrespondents by phone in a final attempt to find out why they had not responded and to encourage them to fill out their questionnaires.

The questionnaire focused on how farmers' markets affect the vendors and the local community. We gathered detailed information on how and why the vendors began selling at farmers' markets, their enterprises, the organizational characteristics of their businesses, and their plans. By examining the characteristics, motivations, and organizational strategies of the vendors, we hoped to understand how farmers' markets bridge the informal and formal economies.

The final population consists of 20 full-time growers, 54 part-time growers and 36 non-growers. Although missing data on items were not a major problem, if a respondent failed to answer a particular question, we excluded that case from any part of the analysis using that item. We distributed a total of 183 questionnaires; 115 usable questionnaires were returned, a 63% response rate. Five respondents did not report whether they were full-time, part-time, or non-growers, and were dropped from the analysis reported here.

Results

Pathways into farmers' markets

Table 1 provides insights into the characteristics of the three groups of vendors. First, both rural and urban vendors participate in farmers' markets. Almost all the full-time growers but fewer than half the non-growers lived in rural areas. Full-time growers typically travelled further to the farmers' market than either the part-time or the non-growers, probably because most of the farmers' markets in our study are in towns and villages.

The full-time growers have used farmers' markets for many years and have longer prior histories of production than do either part-time growers or non-growers (Table 1). On average, full-time, part-time and non-growers have been selling at farmers' markets for 12, 6 and 4 years, respectively, and have been producing any kind of product or service for sale anywhere for 27, 11 and 7 years, respectively.

Table 2 shows vendors' reasons for selling at farmers' markets. The questionnaire presented eleven reasons that tapped a range of social, economic and personal dimensions. Vendors were asked to judge the importance of each of these reasons on a scale ranging from 0 ("not at all important") to 4 ("very important").

Of the four reasons deemed most important across the three groups, the two with the highest mean scores ("We enjoy visiting with customers and other vendors" and "We enjoy doing it") deal with noneconomic dimensions. The third and fourth reasons ("We want extra income" and "Our other income sources are limited") clearly tap economic motivations. Considerably less important reasons were to provide learning experiences for children or to create jobs for relatives or friends (reason numbers 8 through 11).

The response pattern in Table 2 confirms that farmers' markets serve more than purely economic functions for all groups of vendors. Interestingly, of the eleven reasons, only one ("We enjoy doing it") differed significantly in importance across the three groups.

Taken together, Tables 1 and 2 support the contention that farmers' markets bridge

Table 1. Pathways into farmers' markets.

	Full-time Growers	Part-time Growers	Non-Growers	Sig.[1]
Residence (%)				
Rural	95	72	47	p<.05
Urban	5	28	53	
Distance to market (mi)	22	12	14	p<.05
History of selling (yrs)				
At farmers' market	12	6	4	p<.05
Any product, anywhere	27	11	7	p<.05

[1] Statistical significance determined by chi-squared (Residence) and F-statistic (Distance and History).

Table 2. Reasons for selling at a farmers' market (mean importance rating, scale from 0 to 4).

	Full-time Growers	Part-time Growers	Non-Growers	Sig.[1]
1. We enjoy visiting with customers and other vendors	3.17	3.37	3.38	NS
2. We enjoy doing it	2.66	3.26	3.42	p<.05
3. We want extra income	2.90	3.13	3.29	NS
4. Our other income sources are limited	2.01	2.21	2.51	NS
5. We have always sold at the farmers' market	1.63	1.75	1.94	NS
6. We don't have the capital to open another kind of outlet (roadside stand, store, etc.)	1.13	1.77	1.99	NS
7. We have no other options	1.02	1.61	1.60	NS
8. We want a learning experience for our children	1.42	1.57	1.17	NS
9. Make a job for spouse or partner	1.01	1.41	1.37	NS
10. Make a job for child or other relative	0.91	1.34	1.17	NS
11. Make a job for friend or business partner	0.75	0.54	0.39	NS

[1] Statistical significance determined by F-statistic.

the formal and informal aspects of the economy. They accommodate diverse economic and noneconomic motivations among vendors, and they open business opportunities for persons with limited capital while contributing to vendors' personal well-being through participation in local community social life.

Organizational strategies

Vendors' use of farmers markets. The flexibility of farmers' markets as institutions that unite households, businesses and local communities can be seen in the range of organizational strategies that different groups of vendors use. Table 3 shows vendors' varying degrees of attachment to their farmers' markets. On average, full-time and part-time growers reported more market days (average of 18 days and 19 days, respectively) than did non-growers (13 days). Furthermore, 22% of the part-time and 10% of the full-time growers reported more than 30 market days in 1992.

Full-time growers were more likely to sell their products at more than one farmers' market (55%) than either part-time growers (36%) or non-growers (19%). Not surprisingly, three-fifths of the part-time growers and nearly half of the non-growers said they would be out of business or "hurt considerably" if their current farmers' market shut down.

Relative importance of farmers' markets and other outlets. Farmers' markets were the most important outlet for all three groups (Table 3), especially for part-time and non-growers (68% and 59% of sales, respectively). For full-time growers, farmers' markets accounted for only 35% of gross sales, followed closely by roadside stands and pick-your-own operations, which together accounted for 30%, and wholesale outlets (19%). For part-time growers, roadside stands and pick-your-own also were second in importance to farmers' markets, although far behind (15%). For non-growers, craft shows were another important source of sales (21%).

Table 3 also shows the distribution of farmers' market sales among vendors and the fraction of total sales that these sales accounted for. For full-time growers, farmers' markets are an important source of economic livelihood, with 83% reporting more than $1000 in sales in 1992. On the other hand, only 55% of the part-time growers and 48% of the non-growers reported this level of sales. Furthermore, 42% of the non-growers sold less than $500 at the farmers' market.

Although full-time growers reported higher farmers' market sales than the other groups of vendors, these sales represented a considerably smaller proportion of their total sales. Only 37% of the full-time growers reported that the farmers' market accounted for at least one-fourth of the total. In contrast, nearly three-fourths of the part-time growers and nearly two-thirds of the non-growers reported that their farmers' market sales accounted for at least one-fourth of their total sales (Table 4).

These results reflect the fact that selling agricultural products is the main business of full-time farmers. Therefore, sales levels for this group are higher than for other vendors, for whom the farmers' market may not be central to their families' economic livelihood. At the same time, farmers' markets clearly represent just one of many outlets for full-time growers, while for part-time and non-growers it often is the only outlet. Consequently, the fraction of total sales accounted for by the farmers' market is smaller for full-time growers than for either part-time growers or non-growers.

Ownership. Part-time growers and non-growers were more likely than full-time growers to be sole proprietors, as opposed to being in a partnership (Table 4). Although only 16% of the part-time growers and 21% of the full-time growers were women, this is well above the figure of 7.6% for all U.S. farmers (U.S. Dept. of Commerce, 1994). In contrast, 40% of the non-growers were women. The reasons the proportion of women was highest among non-growers is not clear. A lack of capital may keep women out of full-time and part-time farming. Another reason may be that it is easy for non-growers to enter farmers' markets.

Labor. Almost all the full-time and part-time growers relied on family labor in their farmers' market operations (Table 4). On the other hand, 22% of the non-growers had no family assistance. As might be expected, more full-time growers (37%) used hired labor than either the part-time growers (14%) or the non-growers (27%).

Table 3. Vendors' use of farmers' markets.

	Full-time Growers	Part-time Growers	Non-Growers	Sig.[1]
Days at market (average)	18	19	13	p<.05
Vendors selling more than 30 days (%)	11	22	0	NS
Vendors selling at more than one market (%)	55	36	19	p<.05
Vendors who would be out of business or hurt considerably if their current market closed (%)	30	59	47	p<.10
Sales at various outlets as share of total (average, %)				
Farmers' market	35	68	59	p<.05
Road-side stand or pick-your-own	30	16	3	p<.05
Wholesale	19	4	7	p<.05
Craft shows	7	8	21	p<.05
Sales at farmers' market (% of vendors)				
>$1000	83	55	48	p<.05
$500 to $1000	11	22	10	
<$500	6	24	42	
<25% of total sales	63	27	35	p<.05
≥25% of total sales	37	73	65	

[1] Statistical significance determined by F-statistic (Days at market and Sales at various outlets) or chi-squared (all others).

Table 4. Ownership patterns, labor use and plans of farmers' market vendors (%).

	Full-time Growers	Part-time Growers	Non-Growers	Sig.[1]
Ownership				
Sole proprietor	65	87	91	p<.05
Partnership	35	13	9	
Women owners	21	16	39	p<.05
Use family labor	94	98	78	p<.05
Use hired labor	37	14	27	p<.05
Plans				
Leave market within 2 years	16	12	15	NS
Stay at market	63	49	61	
Not sure	21	39	24	

[1] Statistical significance determined by chi-squared.

Plans

It is easy to enter or leave farmers' markets. We did not survey persons who were considering selling at a farmers' market or who had left, but we did gather information about the plans of current vendors. Only a small fraction of the three groups of vendors (12 to 16%) were planning to leave the market within the next two years, whereas many more (49 to 63%) were planning to stay (Table 4). Another 21 to 39% were unsure. The three groups did not differ significantly in this regard.

Discussion

As a social institution and as social organizations, farmers' markets are important and inadequately studied contributors to local economies. As bridges between the formal and the informal sectors of the economy, they enable individual entrepreneurs and their families to contribute to the economic life of their local communities by providing goods and services that may not be readily available through formal, mass markets. Thus, they embody what is unique and special about local communities and help to differentiate one community from another.

Our findings confirm the flexible nature of farmers' markets for full-time growers, part-time growers, and non-farmer entrepreneurs, artisans and craftspeople. For all vendors, farmers' markets served both social and economic functions. However, these distinct groups of vendors displayed different pathways into farmers' markets, and their farmers' market businesses were organized differently.

Full-time growers brought the most prior business experience to the markets. Their farmers' market operations were larger, generated more sales, and used more labor than did those of part-time growers or non-growers. Non-farm entrepreneurs, artisans and craftspeople brought the least prior experience to their markets.

For full-time growers, farmers' markets represented one of several outlets for their products. Although the loss of the farmers' market as an outlet might cause some financial hardship for them, it would not be devastating. In contrast, part-time growers rely heavily on a farmers' market; for many, it is their only outlet, and without it they would go out of business. For many of the non-grower vendors, farmers' markets served both as economic and social arenas. They were more likely than the other two groups to participate in farmers' markets for the enjoyment of it.

The three groups' plans did not differ substantially, although for some vendors, the farmers' markets were a stepping stone to more formal business activities. Farmers' markets serve as structural niches where full-time growers, part-time growers, and non-growers can try out new ideas and products without taking a great deal of risk. In this way, farmers' markets facilitate business start-ups. Although anecdotal evidence from the popular press suggests that this would be a fruitful avenue for research (Sullebarger, 1983), little has been done as yet. Therefore we do not know how many formal businesses are spun off each year from farmers' markets. Furthermore, we know little about the characteristics of these businesses or the mechanisms that helped or impeded their success once they left farmers' markets. Thus we need more research on how farmers' markets function as business incubators.

Many vendors in this survey saw potential for further growth of their farmers' market operations and thus were not planning to leave the market soon. This was particularly true for part-time farmers. Given the riskiness of most agricultural endeavors and the lack of adequate marketing alternatives, farmers' markets may be ideal outlets for many part-time growers.

Within the modern American economy, the role of farmers' markets as a social institution has been overshadowed by a concern with mass production and mass marketing. We know considerably more about the minute workings of large individual producers like General Motors (Keller, 1989), IBM (McKenna, 1989) and General Foods (Ferguson, 1985) and of marketers like WalMart (Walton, 1992) and A&P (Walsh, 1986) than we do about the general characteristics of producer and consumer relations in farmers' markets. In part, institutions like farmers' markets are ignored because the dominant neoclassical economic paradigm is unable to accommodate economic relations that are embedded in local communities. From a neoclassical standpoint, farmers' markets may not make good economic sense. From a community perspective, however, they can nurture local economic development, maintain diversity and quality in products, and provide opportunities for producers and consumers to come together to solidify bonds of local identity and solidarity.

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INSTITUTE NEWS

Dr. Rick Welsh, a former extension associate in the Department of Rural Sociology at Cornell University, has joined the Wallace Institute as a Policy Analyst. He will be the principle researcher in a multi-year study of the industrialization of American agriculture and its implications for sustainability. While at Cornell, Dr. Welsh was a research assistant in the Farming Alternatives Program and a sociology instructor. He has also worked as an agricultural economist in the Foreign Agricultural Service and served in the Philippines as a Peace Corps volunteer.

Stephen Viederman, a member of the Wallace Institute President's Council, has been named to the Advisory Board of Redefining Progress, an organization working on alternative GNP, and to the Advisory Board of the Jobs and Environment Campaign.

Ned Raun, a member of the Wallace Institute's President Council and Executive Director of MidAmerica International Agricultural Consortium (MIAC), has announced that MIAC has established the Programa Cooperativo Mexico/MIAC. The goal of the program is to establish long-term partnerships among Mexican and MIAC institutions, with a dual focus on science and education programs, and business and industry development programs that provide mutual benefit to U.S. and Mexican participants.

William Browne, a member of the Wallace Institute's Policy Studies Program Advisory Committee, is the author of *Cultivating Congress: Constituents, Issues, and Interests in Agricultural Policymaking*. He is also the co-author of *Michigan Politics and Government: Facing Change in a Complex State*. Both books have recently been published by University of Nebraska Press.

Cornelia Butler Flora, a member of the Wallace Institute's Board of Directors, and **Charles Francis,** a member of the Editorial Board of *American Journal of Alternative Agriculture*, recently participated in a week-long postgraduate course on ecological agriculture in Southern Norway. Dr. Francis introduced three learning activities based on barley varieties (component technology), whole farm alternatives, and watershed/community planning. Dr. Flora presented methods for matrix ranking, activities calendars, and other social science approaches to evaluate how farmers and families fit into communities, and how this builds social capital.

The compatibility of domestic birds with a nonchemical agroecosystem

M. Sean Clark, Stuart H. Gage, Laura B. DeLind, and Marian Lennington

Abstract. *We evaluated free-range domestic chickens and geese as components of a nonchemical apple orchard intercropped with potato. Chickens and geese were compatible with the system but provided different benefits and had different requirements. Chickens were omnivorous and highly active throughout the day, and dispersed throughout the available area. In contrast, geese were strictly herbivorous and less active, and usually remained close to their coop and water source. Geese substantially reduced vegetation biomass under the trees and around the potatoes without damaging either crop. Chickens reduced noncrop vegetation biomass slightly but also consumed several insect species, including Japanese beetle and Colorado potato beetle. Factors influencing the feasibility of integrating domestic chickens or geese into agroecosystems are discussed.*

Key words: free-range chickens, free-range geese, apple orchard, potato, intercropping, integration, weed management

Introduction

Increasing interest in developing sustainable food production methods has prompted research into a variety of alternative and traditional agricultural practices such as biodynamic farming, intercropping, companion planting, mulching, manuring, and crop rotation. A common characteristic of these practices is that they integrate multiple production components, each intended to interact with and benefit the entire agroecosystem (Dazhong and Pimentel, 1986; Altieri, 1987; Mollison, 1988; Ruddle and Zhong, 1988; Vandermeer, 1989; Crews and Gliessman, 1991; Dazhong et al., 1992). The benefits of such integrated production methods over conventional production methods can include reduced waste, fewer external input requirements, increased energy efficiency, higher soil fertility, and greater ecological and economic stability (Lockeretz et al., 1981; Wagstaff, 1987; Edwards, 1989; Reganold et al., 1993; Smolik et al., 1993).

Our discussions with farmers in the Great Lakes region of the United States and Canada have revealed that domestic birds are sometimes integrated into organic orchards. Also, the scientific, popular, and local farming literature reports that domestic birds are used as integral parts of orchard and non-orchard systems (Fuan, 1985; Traupman, 1990; Rodale Institute, 1991; Salatin, 1991; Cramer, 1992; Virginia Association of Biological Farming, 1993). However, we have found few experimental investigations of the role that birds play in such systems (Mayton et al., 1945).

This paper reports findings on two objectives of a study of domestic chickens and geese in a potato-intercropped apple orchard: to describe the birds' behavior, and to determine the birds' impact on plants within the system, including crops and noncrops. We also discuss factors that may present opportunities for or barriers to integrating domestic birds into different agroecosystems. Our research on how domestic birds affect insect pest populations, beneficial arthropods, and pest damage is continuing and will be reported in a later paper.

M. Sean Clark is a Graduate Assistant and Stuart H. Gage is Professor, Department of Entomology and the Ecology and Evolutionary Biology Program, Laura B. DeLind is a Senior Academic Specialist, Department of Anthropology, and Marian Lennington is a former graduate student, Department of Entomology, Michigan State University, East Lansing, MI 48824.

Materials and Methods

The orchard system

The study was done on a 0.5-ha block in an apple orchard at Michigan State University's Kellogg Biological Station in the southwestern portion of the state. The orchard was planted in 1983 with the disease resistant varieties 'Redfree,' 'Priscilla,' and 'Liberty' on M.26 rootstocks, and has been managed without pesticides since its establishment. Although the orchard has sustained heavy insect damage during some years, disease pressure has been low. This has allowed the orchard alleys to be used for intercropping annuals, including potatoes, tomatoes, and beans, and for pasturing domestic fowl, including chickens and geese. Under conventional orchard management this would not have been possible because of the intensive spray schedule, which requires using the alleys for tractor traffic. The use of pesticides also would have been incompatible with the birds.

In 1993, Barred Plymouth Rock chickens, a breed of *Gallus domesticus*, and African geese, a domestic breed of *Anser cygnoides* (Silversides et al., 1988), were evaluated as components of an apple orchard intercropped with potato (*Solanum tuberosum* L.). The selection of these birds for the experiment was based on recommendations from area farmers and on small-scale trials with several varieties of domestic birds from 1990 to 1992.

Experimental design

Twelve plots were randomly established in the block for three treatments with four replications. Plots were 16.8 m by 9.9 m, and consisted of three rows of three apple trees and two inter-row alleys (Fig. 1). The trees in two of the rows were 'Redfree,' with 'Priscilla' in the third. The tree spacings were 3.3 m and the row spacings were 6.5 m. The alleys were planted in potatoes ('Red Pontiac') on 18 May with 30-cm plant spacings and 75-cm row spacings. This allowed three rows of potatoes to be planted within each alley with the outside potato rows not directly beneath the canopy of the apple trees. In one randomly selected alley of each plot the potato plants were mulched to 15 cm with recently cut rye (*Secale cereale* var. 'Wheeler') from an adjacent field, creating mulched and unmulched subtreatments. The potatoes were handweeded on 11 June and handweeded and hilled on 17 June.

The three main treatments were: 1) placing 15 chickens per plot (Chicken treatment); 2) placing 11 geese per plot (Goose treatment); and 3) no birds (Control). Plots with chickens or geese were surrounded with 1.5 m plastic fencing with 6-cm mesh. On 2 July, the birds were introduced into the designated plots at 6 weeks of age, with approximately equal numbers of males and females. On 17 July, 3 geese were removed from each plot of the Goose treatment, setting the population at 8 per plot. The birds were maintained in the plots until 6 August.

The birds were kept in coops (1.2 × 1.2-m) at night and released to free range from approximately 7 A.M. to 9 P.M. (EST). The coops were located on either the eastern or western perimeter of the plots (Fig. 1). The birds were provided with small amounts of cracked corn and poultry starter immediately after being released from the coops in the morning, and again approximately 10 min before being put into the coops at night. The purpose of the morning feeding was to train the birds to disperse into the plots to find food, while the night feeding was used to get them to return to the coop. The coop was closed each night to protect the birds from predators. Water was provided in buckets and watering cans and replaced as needed (usually twice per day).

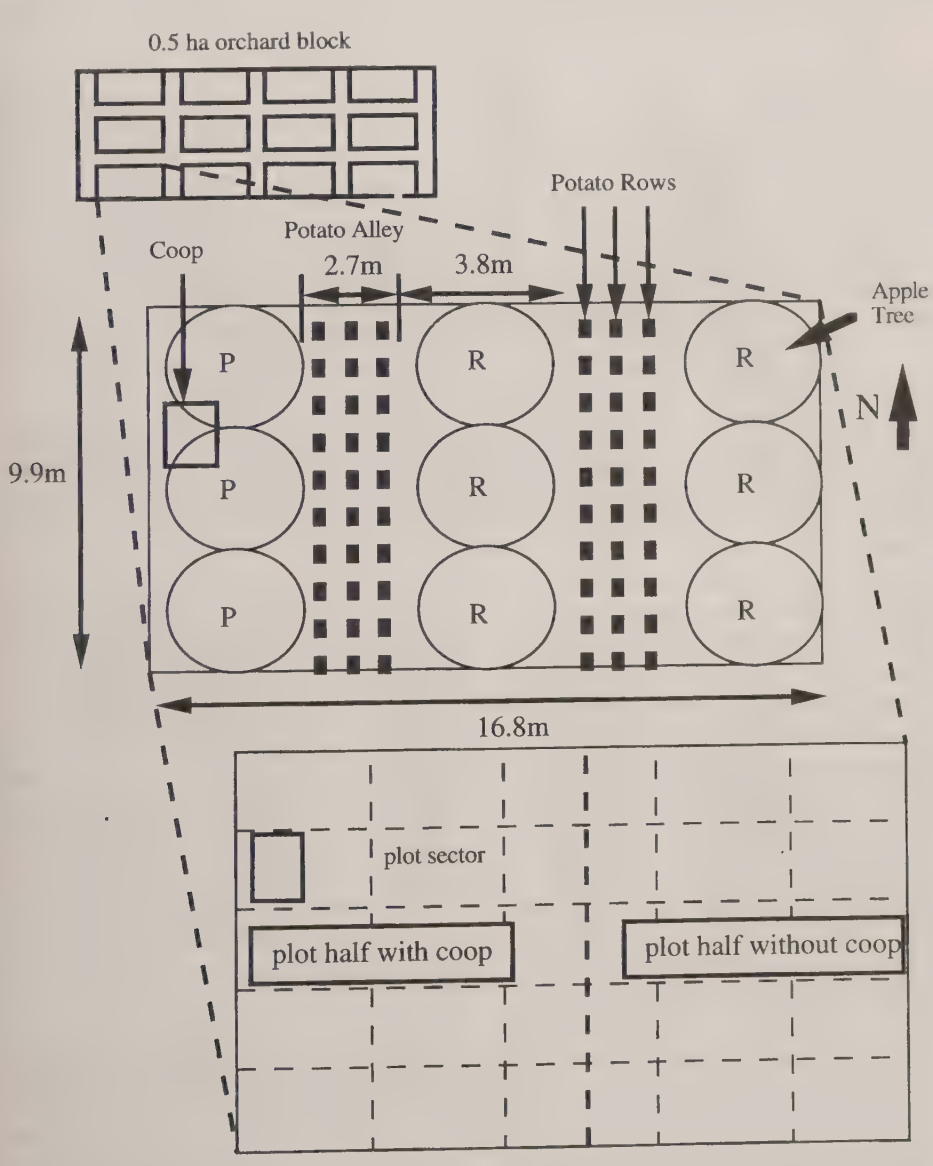

Figure 1. Experimental map showing the plot layout. Apple trees are designated P and R for 'Priscilla' and 'Redfree,' respectively. One randomly selected potato alley of each plot was mulched while the other was left unmulched. Each plot was divided into 25 sectors for estimating bird dispersion and divided in half for measuring their tendency for moving away from the coop.

Behavior observations

We observed the chickens and geese on arbitrarily selected days at arbitrarily selected times between 8 A.M. and 8 P.M., except during rain. Bird behavior was sampled by observing the whole flock of birds in a particular plot for 5 minutes and recording their foraging, drinking, and resting. Because it is difficult to track individual birds for 5 minutes, the entire flock within each plot was treated as the sampling unit rather than individual birds. A total of 12 sets of 5-min observations were collected for each bird treatment. A set consisted of the observations for the four plots per treatment recorded at a particular time and day. These sets were grouped into four periods of 3 hr: morning (8:00 A.M. – 10:59 A.M.), midday (11:00 A.M. – 1:59 P.M.), afternoon (2:00 P.M. – 4:59 P.M.), and evening (5:00 P.M. – 8:00 P.M.). Each observation set from a period served as a replicate for calculating means and standard errors. There were 5, 2, 2, and 3 observation sets for the morning, midday, afternoon, and evening periods, respectively. The frequencies of activity were computed as the fraction of observations in a set in which we observed a particular activity being performed by at least one bird in the plot. When possible, observers also recorded what foraging birds were eating.

Plot maps, which were used to record bird locations within the plots, were divided into 25 sectors (Fig.1). This allowed observers to record simply the presence or absence of birds for each sector. These data were used to estimate bird dispersion throughout the plots, to determine if the birds preferred a particular habitat within the plot (apple row or potato alley), and to measure their tendency to roam to the side of the plot away from the coop. Bird dispersion was determined by calculating the fraction of plot sectors occupied by the birds at a particular time of day (Fig. 1). We evaluated habitat preference by comparing how often birds were observed in the tree row versus the potato alleys. The tendency of the birds to roam from the coop was evaluated by how often the birds were observed in the half of the plot containing the coop versus the half without it (Fig. 1).

Plant sampling

We sampled aboveground, noncrop vegetation biomass in the apple rows and potato alleys on 22 July by cutting at ground level and removing all vegetation within random 1-m^2 quadrats. Weed biomass in the potato alleys was sampled at a single random location along the middle potato row of each subplot. Ground cover biomass within the tree rows was sampled in a single random location in the middle tree row of each plot. Plants were separated into grasses and broadleafs, dried for 48 hr, and weighed. We sampled potato tuber fresh weight on 30 July by digging and weighing all potatoes in the center 2 m of each row, resulting in 6 m of potato row sampled for each subplot. Apple fruit fresh weight was sampled by weighing all fruit from each tree at harvest. Most of the 'Priscilla' trees did not bear fruit. Therefore, comparisons were limited to 'Redfree' trees only. Noncrop biomass, potato tuber fresh weight, and apple fresh weight in the chicken and goose treatments were compared statistically to the control using the one-tailed Mann-Whitney test (Zar, 1984).

Results

The chickens spent consistently more time foraging than resting and drinking, while activities of the geese varied more with time of day (Fig. 2). The chickens foraged throughout the day, whereas the geese did most of their foraging in the morning and evening and least at midday. As may be expected for the geese, resting and drinking were highest at midday. Although we did not observe systematically during rain, we noticed that chickens tended to seek shelter under trees or in the coop during rain while geese appeared unaffected.

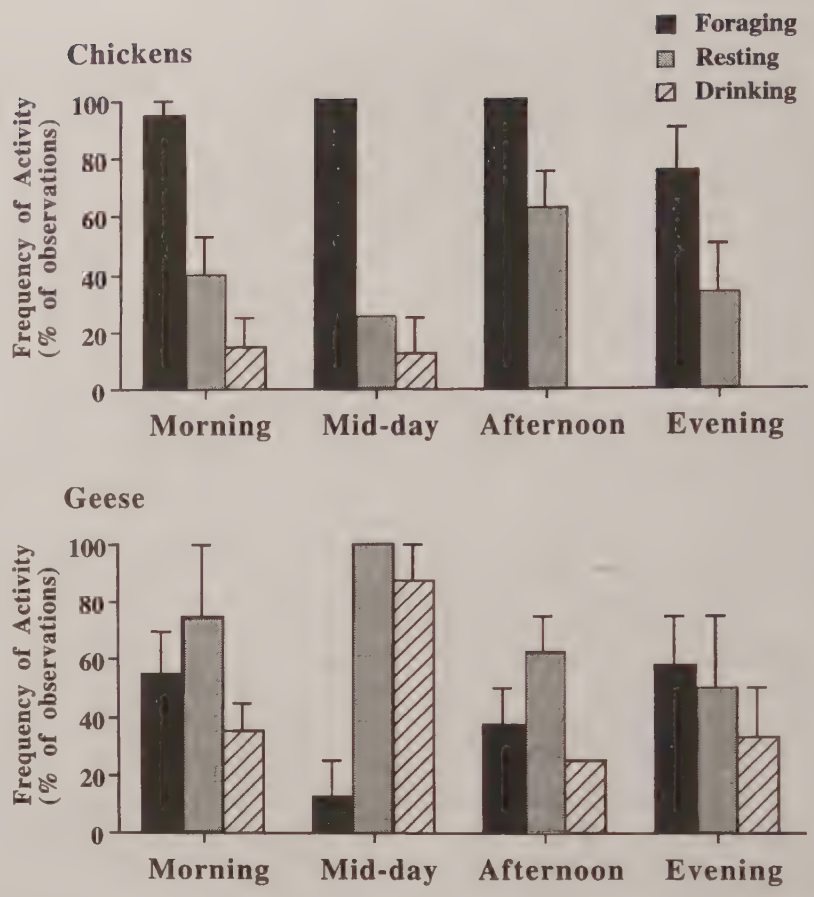

Figure 2. Chicken and goose activity patterns based on the mean percentage of observations in which birds were observed to be resting, foraging, and drinking. The periods are morning (8:00 A.M. – 10:59 A.M., N=5), midday (11:00 A.M. – 1:59 P.M., N=2), afternoon (2:00 P.M. – 4:59 P.M., N=2), and evening (5:00 P.M. – 8:00 P.M., N=3). Error bars are standard errors of the mean.

Chickens consistently dispersed more than geese (Fig. 3). During morning and afternoon observations, chickens occupied between 25% and 35% of the plots, with peak dispersion at 9 A.M. and 10 A.M. Dispersion of the geese peaked at the same time, but the geese remained in a tightly clustered flock occupying less than 15% of the plot. Chickens came together into tighter flocks during midday and evening (Fig. 3).

The chickens and geese consistently occupied apple rows throughout the day (Fig. 4). Chickens also were commonly observed in the potato alleys, in contrast to the geese (Fig. 4). Geese tended to remain in the half of the plot that contained the coop, while chickens roamed consistently on both sides of the plot, especially during midday and afternoon (Fig. 5).

The chickens were omnivorous, feeding on insects and plants, while the geese were strictly herbivorous (Table 1). Chickens fed more frequently on invertebrates on or near the soil surface than on plants. We usually could not see what organisms were being eaten; therefore Table 1 is incomplete, and probably represents only a small portion of the items consumed. Geese fed solely on plants, included grasses and broadleaf species. Interestingly, geese actively pursued some flying insects for short distances (less than 1 m); however, no successful catches were observed. We did not quantify food preferences, but the geese seemed to prefer grasses (Poaceae spp.), common dandelion (*Taraxacum officinale*), and common plantain (*Plantago major*). They ate common

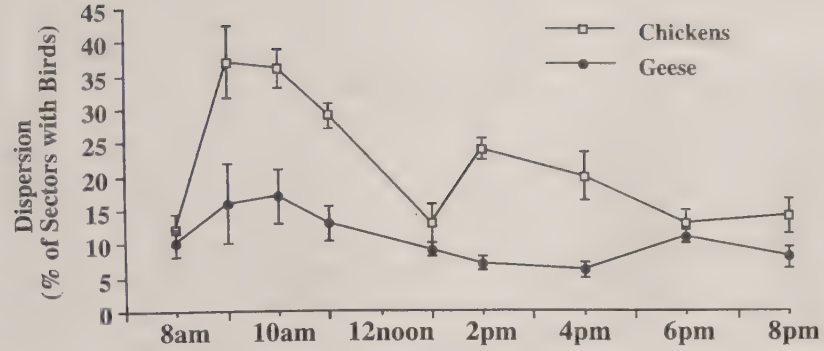

Figure 3. Chicken and goose dispersion within the orchard plots as indicated by the mean percentage of plot sectors occupied by birds at arbitrarily selected times of day in one month (N=4 for each mean). Error bars are standard errors of the mean.

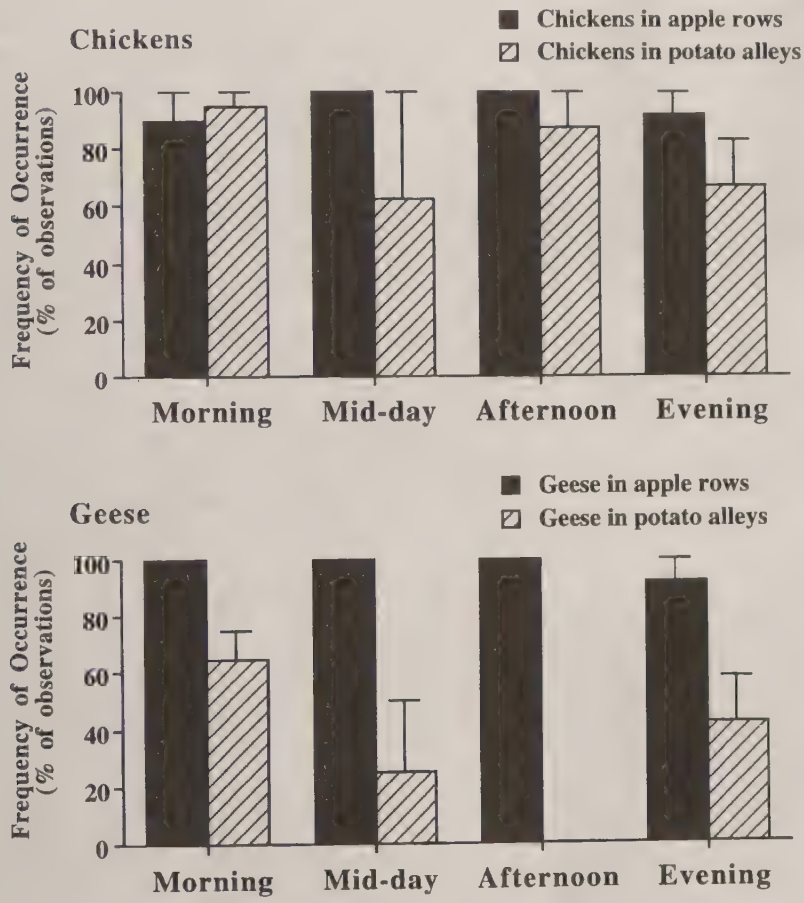

Figure 4. Frequency of chicken and goose occurrence in the apple rows and potato alleys as indicated by the mean percentage of observation periods in which the birds were observed in these habitats. See Fig. 2 for periods and number of observations.

ragweed (*Ambrosia artemisiifolia*) and common lambs-quarters (*Chenopodium album*) only when preferred plants were unavailable. Canada thistle (*Cirsium arvense*) was eaten only as a seedling. Although chickens and geese were seen feeding on unearthed potato tubers, neither fed on potato plants. Occasionally, geese fed on apple leaves on low-hanging branches and on recently dropped fruit. By contrast, chickens fed on low-hanging fruit on the trees, but were never seen in the trees feeding on fruit.

Groundcover biomass in the tree rows was substantially reduced in the goose treatment compared to the control (Fig. 6), primarily because of a reduction in grass. This supports our observation that grasses were a preferred forage. Ground cover biomass was slightly lower in the chicken treatment, but the difference was not statistically significant. Similarly, weed biomass in the potato alleys was slightly reduced in the chicken treatment and substantially reduced in the goose treatment compared with the control (Fig. 7).

Although weed biomass in the potato alleys varied considerably across the treatments, potato tuber yields were statistically similar among the treatments. The pooled mean yield for the three treatments was 1.03 kg per m of potato row (equivalent to 4754 kg per ha of intercropped orchard). The lack of treatment effect was probably due to the extensive hand weeding in all treatments before the birds were introduced, giving the potato plants in all three treatments a competitive advantage over the weeds (Bellinder and Wallace, 1991). Colorado potato beetle (*Leptinotarsa decemlineata*), the most important potato pest in Michigan, was not present in this experiment until late July (more than 60 days after planting) and, therefore, probably had no influence on yield (Zehnder and Evanylo, 1989).

Apple yields in all treatments were low in 1993 because of a lack of fruit thinning, which has caused the orchard to alternate between years of high and low yields. Mean fruit yield was greater in the chicken and goose treatments than in the control, but the difference was statistically significant only for the goose treatment (Fig. 8). This yield increase was apparently due to the reduction in weed competition in the goose treatment (Rupp and Anderson, 1985; Raese, 1990).

Discussion

If we assess the compatibility of the birds in this agroecosystem only on ground cover management and weed control, the geese appear ideal. However, many other factors, some of which were addressed in this study, need appropriate consideration. The compatibility of the birds in any agroecosystem will depend on some factors that are general and predictable and others that are local

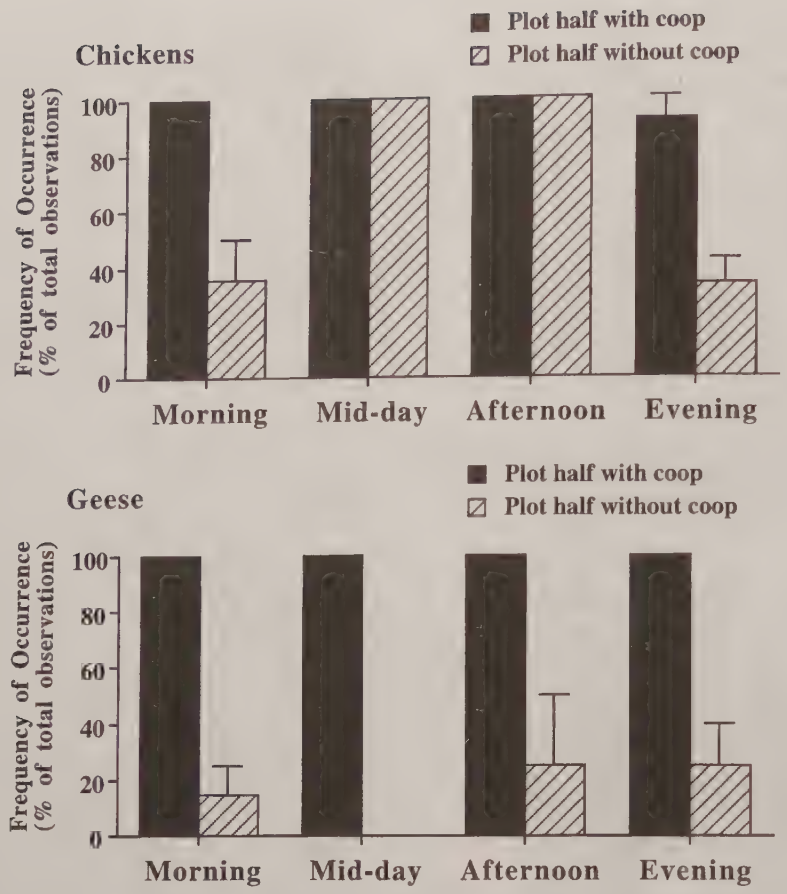

Figure 5. Frequency of chicken and goose occurrence in the plot half with the coop and the half without the coop as indicated by the mean percentage of observation periods in which the birds were observed in these areas. See Fig. 2 for periods and number of observations.

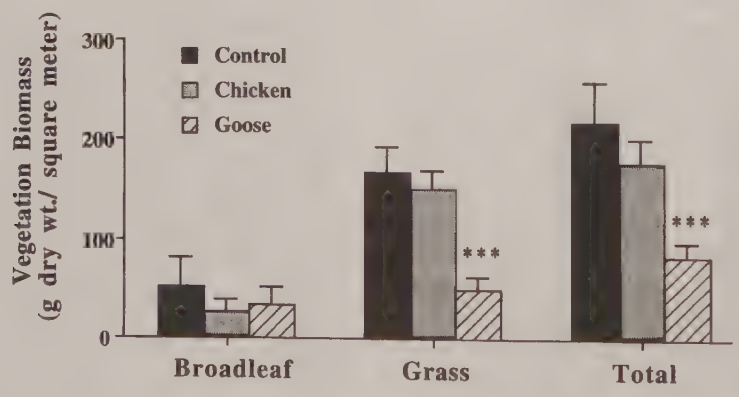

Figure 6. Aboveground vegetation biomass (g/m^2 dry wt) in the tree rows under the three treatments. Total biomass is broken down into grass and broadleaf weeds. Asterisks indicate the level of statistical significance (see Materials and Methods) of the difference between the control and each bird treatment (one-tailed Mann-Whitney test). Error bars are standard errors of the mean. *, **, and * indicate p<.05, p<.025, and p<.01, respectively.**

and unique. In this study, plots were small and the results are not likely to represent those obtained on larger plots. Mayton et al. (1945) observed that chickens and geese controlled nutgrass effectively in small plots of cotton but inadequately in large plots because they would not range far enough from the coop. However, this problem may be managed by rotational grazing within smaller paddocks.

According to Gillen and Scifres (1991, p. 370), "the successful use of . . . selective grazing is more an art than a science, which usually disallows quantifying necessary procedures to reach an end result except in selected cases." Several variables in this study, including bird density, bird age, paddock size, supplemental feeding, and date of introduction, could have a substantial influence on experimental grazing evaluations, but it was not feasible to evaluate all possible combinations. We chose values for these variables based on our previous experience and limitations. However, they are not necessarily the optima for this system or any other.

According to Mollison (1988), the suitability of introducing domestic birds into a production system depends upon three factors: 1) the behavior of the birds; 2) the nutritional requirements of the birds and the provisions within the system; and 3) the interactions between the birds and the rest of the system, including the crops, noncrop plants, other animals, and people. If compatibility is evaluated according to these criteria, then the differences between the chickens and geese become more obvious than the similarities. The chickens are omnivorous, while the geese are herbivorous. The chickens were active throughout the day, stayed well dispersed, and required little human attention and labor. In contrast, the geese were active mostly during the morning and evening and stayed in a flock that was less inclined to move away from the coop. However, when foraging, the geese consumed large amounts of vegetation. The geese also consumed large amounts of water, which meant they required considerable human attention and labor.

The spacious and complex environment within the orchard provided for the birds' welfare better than would be possible under conventional bird production systems (Appleby and Hughes, 1991). The trees provided shade for the chickens and geese and roosting places for the chickens. We did not determine if the food provided by the system would be adequate to sustain the birds without supplemental feeding. To address this question would require knowledge of the specific objectives of the farmer. If the goal was to maximize the use of the birds to manage ground cover or weeds, supplemental feeding could be kept low or possibly even eliminated. If the birds were intended for egg production or to be sold as meat,

Table 1. A list of food items observed to be consumed by chickens and geese in the potato-intercropped apple orchard in 1993.

Common Name	Scientific Name	Notes[1]
Eaten by chickens		
Colorado potato beetle	*Leptinotarsa decemlineata*	adults
Japanese beetle	*Popillia japonica*	adults
ant	Formicidae spp.	adults, larvae
ground beetle	Carabidae spp.	adult
rove beetle	Staphylinidae spp.	adult
tomato hornworm	*Manduca quinquemaculata*	larvae
apple	*Malus pumila*	fruit on tree or on ground
potato	*Solanum tuberosum*	unearthed tubers
grass	Poaceae spp.	
birdsfoot trefoil	*Lotus corniculatus*	
earthworm	Lumbricidae spp.	
Eaten by geese		
grass	Poaceae spp.	
common dandelion	*Taraxacum officinale*	
common plantain	*Plantago major*	
common lambs-quarters	*Chenopodium album*	
redroot pigweed	*Amaranthus retroflexus*	
common ragweed	*Ambrosia artemisiifolia*	
Canada thistle	*Cirsium arvense*	seedlings
curly dock	*Rumex crispus*	
apple	*Malus pumila*	fruit on ground
potato	*Solanum tuberosum*	unearthed tubers
bean	*Phaseolus vulgaris*	

[1] Indicates the specific life stage or part of the item consumed or the circumstances during the consumption.

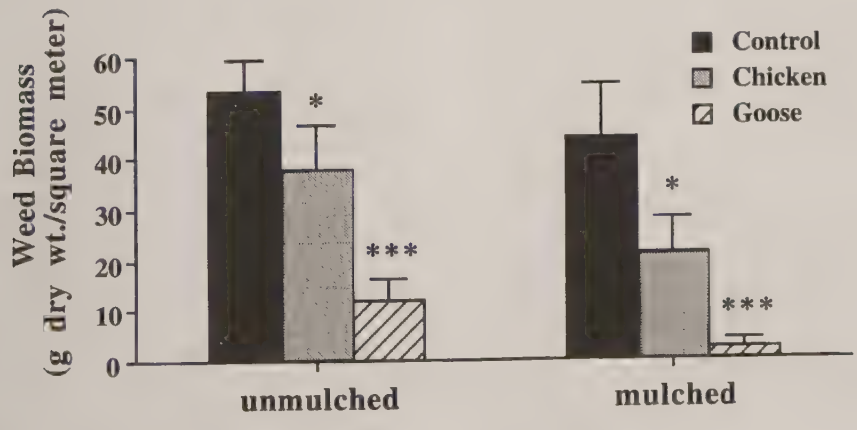

Figure 7. Aboveground weed biomass (g/m^2 dry wt) in mulched and unmulched potatoes under the three treatments. Asterisks indicate the level of statistical significance (see Materials and Methods) of the difference between the control and each bird treatment (one-tailed Mann-Whitney test). Error bars are standard errors of the mean. *, **, and * indicate p<.05, p<.025, and p<.01, respectively.**

considerable supplemental feeding would be required.

The interactions between the geese and weeds suggest that geese could be managed as weed control agents under varied circumstances, but chickens would need to be stocked at a greater density than was done in this experiment. However, besides weed control, chickens may provide biological control for some insect pests. They were observed to feed commonly on Japanese beetles (*Popillia japonica*) and occasionally feed on Colorado potato beetles. Although chickens have been described as effective insect predators (Hoare, 1928), there is some evidence that certain insects, including Colorado potato beetle, are unpalatable (Hough-Goldstein et al., 1993). However, we found that chickens in this study readily consumed Colorado potato beetles, even when other foods were available.

Assuming it is feasible to provide adequate attention and a reliable source of water, chickens and geese seem highly suitable for this experimental agroecosystem according to Mollison's criteria. However, ecological compatibility alone does not mean economic feasibility under current market conditions. Although it is difficult to assess the economics of an experimental system such as this, several characteristics may make it feasible to introduce birds. If rotational grazing can be used effectively, the birds might eliminate the need for herbicides or mowing, which can represent a substantial portion of production costs. For example, in a small low-input apple orchard that relied on mowing and mulching for weed control, these operations accounted for 25% and 40% of total labor and material costs, respectively (Prokopy, 1991). Although the birds do require a high level of human attention, they could be managed to provide marketable products, such as eggs and meat, which could offset the labor costs. In addition, the birds could play an important role in nutrient cycling, thereby reducing the need for external fertilizers. Clearly, the scale of the farming operation will have an important influence on the feasibility of introducing domestic birds. Domestic birds in orchards or other agroecosystems require close human management for protecting the birds and crops and for using the birds efficiently. This makes bird integration more amenable to operations that already use high labor inputs.

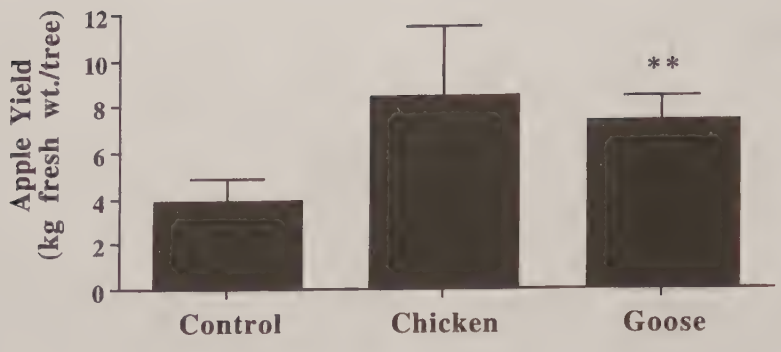

Figure 8. Apple fruit yield (kg fresh wt. per tree) for 'Redfree' trees under the three treatments. Asterisks indicate the level of statistical significance (see Materials and Methods) of the difference between the control and each bird treatment (one-tailed Mann-Whitney test). Error bars are standard errors of the mean. *, **, and * indicate p<.05, p<.025, and p<.01, respectively.**

Nevertheless, the willingness to provide additional labor or use available labor in new ways must be justified. Integrating domestic birds or other animals because of a commitment to more biologically balanced or chemical-free agriculture may not be sufficient if there is no way to use the resulting production diversity. Production methods do not exist apart from the organization of food systems, but rather are bound up with them. Thus, a farming operation primarily intended to supply the family with food will respond differently from a commercial operation competing in a few externally controlled markets.

In keeping with this premise, there is a logical connection between the integrative methods reported here and the operation of localized food production and distribution. Community-based agricultural arrangements in which nonproducers take an active interest in how their food is grown, perhaps also providing labor, potentially are well suited to more integrated and diversified production. Local or regional markets that can dispense with the cost and waste of food packaging and advertising can accommodate the more varied and less standardized foods produced without agrichemicals. There is, of course, much behavioral inertia to be overcome if such community-based food systems are to have a greater role in U.S. agriculture.

The development of ecologically based, nonchemical food production systems will require agroecosystems to be more energy efficient and economically stable, produce less or no pollution, require less therapeutic intervention to maintain pests at acceptable levels, and be compatible with the needs and values of the producer and consumers (Edens and Haynes, 1982; Vereijken, 1989; Hill and MacRae, 1992). Although these criteria have been used in designing this experimental agroecosystem, farmers undoubtedly will put different emphasis on each criterion. Our objectives were to start to understand the interactions between three components: domestic birds, potato plants, and apple trees. Although this experiment suggests that these components are compatible and may benefit each other in various ways (Fig. 9), the practicality of such a system from a farmer's perspective will ultimately depend on a variety of social, economic, philosophical, and organizational factors both within and beyond the farm.

Acknowledgments. We thank Stephanie Clark, Hugh Atkinson, and Kristen Hobbie for field assistance. We also thank Jeff Dlott and Mark Van Horn for providing useful comments on an earlier draft. Funding for this research was provided by the North Central Region SARE and ACE programs.

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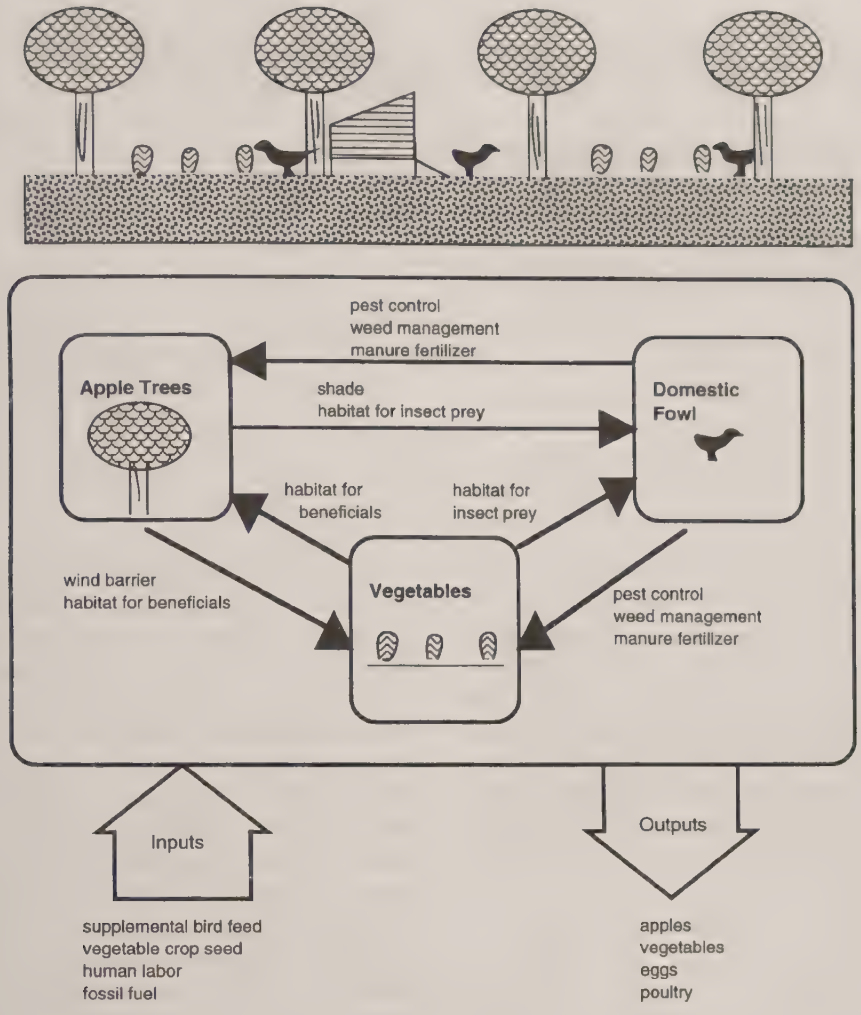

Figure 9. Conceptualization of an integrated agroecosystem based on the experimental agroecosystem in this study. The arrows indicate the potential beneficial interactions between the components of the system.

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ARS Targets Fruit Growers in Northwest For IPM Program

The USDA's Agricultural Research Service, in an effort to place 75 percent of all U.S. acreage under some form of integrated pest management (IPM) by the turn of the century, has implemented an areawide pest management initiative with fruit growers in the Pacific Northwest. The first program is targeted at the codling moth by incorporating IPM technologies that have had only limited practice in individual orchards, and applying them in contiguous orchards owned and managed by several growers, according to an article in *Agricultural Research* (July, 1995).

While the main tactic for suppression of the codling moth will be mating disruption, other tactics will include Bacillus thuringiensis (Bt) sprays, and parasite and sterile male codling moth releases over large areas. For information, contact Robert M. Faust, USDA-ARS National Program Staff, Bldg. 005, 10300 Baltimore Ave., Beltsville, MD 20705-2350; (301) 504-6918.

Minnesota extension agents' knowledge and views of alternative agriculture

Deborah D. Paulson

Abstract. *I interviewed 19 county agricultural extension agents about their views of alternative agriculture as it is being promoted by sustainable agriculture groups in Minnesota. They varied considerably in how much they knew about it, their openness to it, and how heavily they were involved in it. County extension agents share broad economic and environmental goals with sustainable farming advocacy groups, but many believe that agriculture is already working to meet those goals and are skeptical of the feasibility of alternative agriculture. Extension agents generally did not accept as realistic a primary social goal of sustainable agriculture advocates: maintaining the number of family farms. If county extension agents and sustainable agriculture groups in Minnesota are to work together for more sustainable agriculture, open discussion is needed on the goals of agriculture and visions for its future.*

Key words: sustainable agriculture, Minnesota

Introduction

In 1995, agricultural professionals in the Cooperative Extension Service, Natural Resource Conservation Service and other agencies will begin to receive training in sustainable agriculture through various regional projects funded by the 1994 Sustainable Agriculture Research and Education (SARE) grants. "Training the trainers," as the call for proposals describes it, (U.S. Dept. of Agric., 1994), is perhaps an inappropriate phrase because it implies that technical knowledge is being transferred from those with knowledge of sustainable agriculture to those without it. Agricultural professionals already have some knowledge of sustainable agriculture, and have views that depend to some extent on their values and world view (Buttel et al., 1986; Burkhardt, 1991). The success of educational programs in sustainable agriculture will depend on the knowledge, beliefs and values the students bring to them.

The national debate over what constitutes sustainable agriculture has been described in terms of competing paradigms of agriculture (Dahlberg, 1986; Beus and Dunlap, 1990; Curry-Roper, 1992; Hamlin and Shepard, 1992; Schaller, 1993). The conventional view holds that sustainability can be achieved without fundamental changes in the current system. The alternative view is that sustainability cannot be achieved without a far-reaching transformation of the structure and philosophy of agriculture, as well as its practice (Berry, 1977; Madden, 1987; Strange, 1988; Land Stewardship Project, 1992a).

There have been several large-scale surveys of attitudes of agricultural professionals toward sustainable agriculture (Buttel and Curry, 1992; Dunlap et al., 1992; Padgitt and Lasley, 1993), but little has been done to explore more deeply their knowledge and views of sustainable agriculture. This study presents the results of in-depth interviews with county agriculture extension agents in Minnesota. Because county extension agents play a direct role in conveying information among farmers and between the university and farmers, their views are important in determining the direction agriculture takes. After I present the results of these interviews, I discuss the implications for furthering the role of extension agents in promoting the development of sustainable agriculture.

A clarification is needed of the terms "alternative agriculture" and "sustainable agriculture." I use these terms interchangeably in this paper to refer broadly to the alternative paradigm for agriculture described by Beus and Dunlap (1990). As described below, county extension agents may not share a similar conception of these terms, but they are aware of this use of them. In the interviews, I used "alternative agriculture" to emphasize a model of sustainable agriculture that was significantly different from conventional agriculture.

Methods

During the summer of 1992, I personally interviewed 19 county agricultural extension agents in Minnesota. Twenty counties were selected from the 62 Minnesota counties that had been identified as strongly agricultural on the basis of number of farms and fraction of land in agriculture (Menanteau-Horta et al., 1993). Twenty-five northeastern and urban counties that are not primarily agricultural were excluded. I selected a stratified random sample of counties from each of the following regions: 1) southern:

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mainly corn, soybeans and hogs (8 selected out of 25 counties in the region); 2) central and southeast: mainly dairy and cattle (8 of 24 counties); and 3) northwest, mainly small grains (4 of 13 counties). The Assistant Director of Agriculture for the Minnesota Extension service sent a letter to all county agricultural agents telling them of the upcoming survey and encouraging them to participate if selected. I also sent a letter informing agents of the study and my intention to contact 20 randomly selected agents. I arranged personal interviews with county agricultural agents in 19 of the 20 selected counties in June and July 1992. I could not arrange an interview with one agent in the southern region. In the two counties that had two agricultural agents, I selected one who was most involved with the dominant type of agriculture in the county.

A structured, entirely open-ended questionnaire was used (Sudman and Bradburn, 1982). A structured rather than a semi-structured instrument was chosen to minimize the influence of question phrasing and order (Bernard, 1994). Open-ended interviews have the advantage of allowing the respondents to provide answers in their own words, or even to challenge the question. I added clarifying questions and probes as necessary. This lets the researcher gain a much better understanding of the foundations and interconnections of respondents' attitudes and knowledge than is possible with questionnaires of preselected answers (closed questionnaires).

The main disadvantage of open-ended personal interviews is the greater time required to conduct and analyze the interviews, which limits the number that can be done. A sample of 19 is small, but it makes up 30% of the strongly agricultural counties in Minnesota, so the results are probably representative of agricultural agents in the state and the institutions where they received their educations. Most of the types of agriculture found in the upper Midwest are represented in Minnesota (Sommer and Hines, 1991), but the social milieu and ideology of agriculture probably vary within the upper Midwest. However, a study of land-grant faculty members from Washington State found conceptions of sustainable agriculture similar to those found in this study (Dunlap et al., 1992). These views *may* be representative of a wider area where the family farm has dominated, but probably not areas with a different agricultural structure (Troughton, 1985).

I tested the interview instrument on one county agricultural agent and made minor changes for clarity and to facilitate flow. Major interview topics were addressed in the following order:

1. main problems facing agriculture in the county;
2. agent's understanding of alternative agriculture and related terms;
3. a first definition of alternative agriculture introduced by the interviewer that emphasizes reducing off-farm inputs through management but does not address social concerns;
4. agent's assessment of alternative agriculture practices in the county using this definition;
5. agent's sources of information and involvement in alternative agriculture;
6. agent's views on the economic and environmental goals of alternative agriculture and its potential to meet those goals;
7. agent's views on farmer-run research and the role of extension;
8. agent's views on social goals of maintaining family farms and rural communities in the Midwest and the potential of alternative agriculture to meet those goals;
9. agent's general views on the alternative agriculture movement in Minnesota and the Midwest;
10. personal background of the agent;
11. invitation to ask questions or add anything to the interview.

Each interview lasted from 45 minutes to 2 hours, with most taking about 1-½ hours. I took notes during the interviews and tape recorded them. Where answers could be coded I give breakdowns, but without drawing any statistical inferences.

All but 3 of the 19 agents had or were working on a Master's degree, and 12 had at least one degree in Adult or Agricultural Education. Twelve had at least one degree from the University of Minnesota in St. Paul, with all but 2 of the other degrees from North Dakota State University or Iowa State University. All but three agents grew up on a farm, and all but three grew up in Minnesota. Only one agent interviewed was female. (At the time of the interviews there were 5 or 6 [one name was ambiguous] female county agricultural extension agents in the state out of a total of 91.) There were no clear differences among the responses according to the agents' age, education or region. Therefore, the results are presented for the aggregate sample.

Results

Concepts of sustainable and alternative agriculture

Before giving the county agents a definition of alternative agriculture to work with during the interview, I asked them what they thought the terms "sustainable agriculture," "low-input sustainable agriculture (LISA)," and "alternative agriculture" meant. Most agents' definitions of "sustainable agriculture" included maintaining farm profits in the long and short run and using environmentally sound or resource-conserving practices. Four included "socially acceptable" as part of the definition of sustainable agriculture. About half the agents also included keeping chemical inputs to the minimum necessary to maintain yields and profits. Although all agents were aware that some definitions of sustainable agriculture include a reduction in use of purchased chemicals, some personally rejected that idea. Of the eight who differentiated between sustainable agriculture and LISA, most tended to view the former more positively because it did not require low use of inputs. They thought that lower use of inputs may not always be desirable or sustainable. A majority believed that alternative agriculture referred mainly to alternative crops.

For the remainder of the interview, I asked the county agents to consider "alternative agriculture" (the term I used throughout the interview) to be "any methods that: 1) differ from the methods conventionally used on most land in this area; 2) include the goal of conservation of soil, water, energy and/or biological resources; and 3) include the goal of reducing use of off-farm inputs through the improved management of natural processes such as nutrient cycling, nitrogen fixation and predator-prey relations." This is a paraphrase of the definition used in the widely cited book *Alternative Agriculture* (National Research Council, 1989). I then asked each agent what methods that fit the above definition were being tried or could be used in their counties.

The farming practices that county extension agents listed indicate how agents

conceive alternative agriculture (Table 1). Reduced tillage or no tillage, mentioned by 18 of the 19 agents interviewed, was by far the most frequently cited practice. The next most frequently mentioned alternatives related to pest control. Integrated pest management, mechanical weed control, and post-emergent herbicides were each mentioned by seven agents. Soil testing and manure management were the most frequently mentioned nutrient management practices. Various other practices often promoted by sustainable agriculture groups in Minnesota (Liebman, 1992), including rotational grazing, increased crop rotation, and cover crops, were mentioned by five or fewer agents.

Table 1. Alternative agricultural practices mentioned by county extension agents as either being used or with potential for use in their counties (n=19).

Practice	No. Mentioning Practice
Reduced or no tillage	18
Integrated pest management	7
Mechanical weed control	7
Use of post-emergent herbicide	7
Manure management	6
Soil testing/fertilizer management	6
Rotational grazing	5
Biotechnology	4
Increased or improved crop rotation	3
Ridge tillage	3
Strip cropping, cover or smother crops	3
Banding of herbicides	3
Seasonal milking	2
Organic production	2
Solid-seeding soybean	1
Summer fallow (return to)	1
Self-policing of drug use for hogs	1

Information sources and involvement in alternative agriculture

As expected, given their place in the land-grant system, agents relied most heavily on university research for their information on alternative agriculture, but over half also received information from sustainable agriculture organizations (Table 2). Several other sources, including farm publications, USDA agencies and practicing farmers, were cited much less frequently.

When asked which source was most useful, nine agents said research from the university, four said all sources of information, and the others gave a variety of answers. Many agents indicated sometime during the interview that they valued university research as the most scientific and unbiased source of information. As one agent expressed it:

> Some of those centers [sustainable agriculture organizations from whom he received mail] are good too, they give you some ideas, but when it really comes down to . . . me giving advice or developing a program, I gotta go with the research-based material that the university provides. I mean that's my bread and butter. . . . [I need] unbiased research-based information.

A few said that research done by proponents of sustainable agriculture tends to be anecdotal and often is biased because only positive results are reported.

Most agents were familiar with several sustainable agriculture organizations (Table 3), and most interacted with or at least received information from nearby sustainable agriculture organizations. The only three agents who did not were from the Northwest region, where there were no such organizations. Agents usually interacted with sustainable farming organizations centered in their own counties, although involvement varied greatly. One regional organization with which many agents were familiar was the Sustainable Agriculture Committee of the Southwest Farm Business Management Association, which is associated with a University Experiment Station.

Among state-level programs, agents were most familiar with the Minnesota Extension Service's Integrated Pest Management Program, and seven were directly involved with it. Two other well-known statewide organizations were the Land Stewardship Project and the Minnesota Department of Agriculture's Energy and Sustainable Agriculture Program. The Minnesota Food Association, which promotes dialogue among the University of Minnesota researchers, consumers and farmers, was the least well known of the statewide organizations. Many agents received information from the Organic Growers and Buyers Association and directed interested farmers to it, but none were directly involved with it.

Table 2. Sources that county extension agents mentioned they used for information on alternative agriculture (n=19).

Information Source	No. Mentioning Source
University research	18
Sustainable agric. organization	11
Farm publications	7
U.S. Dept. of Agriculture	5
Practicing farmers	4
Energy & Sustainable Agric. Prog., Minnesota Dept. of Agriculture	3
European experience	2
Agribusiness professionals	2
Other	4

National organizations that promote alternative agriculture were less well known than local and state organizations. Many agents were familiar with the Rodale Institute, but an equal number knew only its name or had never heard of it. Very few had heard of the International Association of Sustainable Agriculture and none were familiar with its activities or publications.

The agents varied a great deal in their level of involvement with alternative agriculture. One was involved in many sustainable agriculture projects related to environmental goals. Another worked closely with one of the Sustainable Farming Associations. However, in 1992, most agents did not participate much in the sustainable agriculture organizations that were not affiliated with the land-grant system, although they were aware of some of their activities. A few knew little about sustainable agriculture as promoted by the main advocacy groups in the state and nation. However, all agents were involved in soil conservation, integrated pest management, or water quality projects at the county or state level.

Table 3. Level of interaction or familiarity of county extension agents with organizations involved in sustainable agriculture (n=19).

Organization/Agency	Interaction/ Involvement	Receives Information	Recognizes Name Only	Not Familiar
Local or regional[1]				
Ridgetiller associations	4	11	3	1
Sustainable Farming Assoc. of Minnesota	3	6	2	8
S.W. Minn. Farm Business Mgmt. Assoc., Sustainable Agriculture Committee	2	9	0	8
Any local or regional organization	8	8	2	1
State				
Minnesota Extension Serv. IPM Program	7	12	0	0
Land Stewardship Project	4	13	2	0
Energy & Sustainable Agric. Prog., Minnesota Dept. of Agriculture	2	16	1	0
Minnesota Food Association	1	5	5	8
Organic Growers & Buyers Association	0	12	5	2
Any state organization	9	10	0	0
National				
Rodale Institute	1	9	7	2
International Assoc. of Sustainable Agric.	0	0	5	14
Any national organization	1	9	8	2

[1] Not all counties in state have active associations

Views of goals of alternative agriculture

Most county extension agents agreed with the broad economic and environmental goals often included in definitions of sustainable agriculture. Many felt that conventional agriculture was already doing a lot to meet those goals. I asked the agents to what extent they agreed with the following list of economic and environmental goals: 1) maintain or improve the profitability of the farm; 2) provide an adequate food supply; 3) maintain or improve agronomic resources, such as soil; 4) assure safe surface and groundwater supplies; 5) minimize threats to human health; 6) reduce consumption of nonrenewable resources such as fossil fuels; and 7) maintain or improve wildlife habitat. Almost all said they agreed with all these goals. One agent said that food supply was more than adequate and that cheap food should not be a goal of agriculture. A few said they agreed with maintaining, but not improving, wildlife habitat. Most noted that pheasant, fox and deer populations (and wolf and moose in the far northwest) had increased since the introduction of the Conservation Reserve Program. Several agents expressed concern over wetlands legislation that was affecting farmers' ability to drain land or to maintain drains on former wetlands. They believed that the public did not understand the situation of farmers and that Minnesota's Department of Natural Resources had been given too much power over private wetlands. One agent, however, believed that new regulations were the only way to make farmers adopt needed practices. Except possibly for wildlife habitat, the agents accepted most of the economic and environmental goals associated with alternative agriculture.

Although several agents emphasized that conventional agriculture is working to meet both environmental and economic goals, farm profits were the primary concern of the majority. When asked early in the interview to name the main problems facing agriculture in their county, 14 of 19 mentioned farm profits first, and three mentioned environmental problems first. Thirteen did not mention any environmental problems as among the most serious, but four mentioned anti-agriculture (environmental) legislation. On the other hand, when asked about specific environmental problems, such as wind and water erosion and surface and groundwater pollution, all but two said that at least one of these was a serious problem in their county. Most agents were involved in projects concerned with soil loss and water pollution.

The agents were much less accepting of the social goals of sustainable agriculture. They were asked to respond to the following statement: "Some people believe that to be sustainable, agriculture must include social, as well as environmental and economic goals. Social goals in the Midwest usually include maintaining the number of family farms and revitalizing rural communities. To what extent do you agree or disagree with the goal of maintaining the number of family farms?"

All but five said that they sympathized with the goal of maintaining the number of farmers. However, all but one considered the goal impossible or unrealistic. Most noted that the profit for farming was too low for families to support themselves today on a small acreage. Many thought that people had to accept the changes occurring in the structure of agriculture, and several said that technological advances required larger and fewer farms. Some regarded the expansion of farms and the decline in the number of farmers as a natural economic process. Most said that agriculture is a business. Expressing a common sentiment, one agent said:

> If we had a farm on every quarter section again . . . I think it would be great for rural America. But, you know, everything is economically driven, and no matter what we've done . . . it hasn't changed things. So, until food gets so high that we can make a better living with less land . . . I don't know.

Several agents challenged the vagueness of the term "family farm." As one agent explained:

> The family farm I see in the future is like some brothers up here where they have 3 to 5 thousand acres. One specializes as a dairy producer; one specializes [in] a very sophisticated use of computers, uses technology, uses 4-wheel drive equipment, so forth. We've gone down in the number of farms [for a long time] and I'm not sure we can reverse that trend or if we *really*, if we really think about it, if we

really want to — maybe we do, but . . . [no ending].

Several agents believed strongly that social and ethical considerations should not be imposed on the market process. A few reacted negatively to what they perceived as the quasi-religious nature of some sustainable agriculture advocacy groups. A few challenged the idea that having many smaller family farms is more socially valuable than having fewer but more profitable large farms. Only one agreed without qualification with the goal of maintaining the number of family farms. However, all but two agents agreed with the goal of strengthening rural communities.

Perceived potential of alternative agriculture

When asked whether reducing off-farm inputs through improved management of on-farm processes could help achieve the economic and environmental goals with which they agreed, most agents said it could help. They identified many of the same attitudinal, structural and policy barriers to meeting both economic and environmental goals through improved use of on-farm resources as have advocates of sustainable agriculture (Table 4). Unlike many proponents of sustainable agriculture, however, many regarded economic constraints as most significant. Many said that methods that substitute on-farm resources and processes for purchased pesticides and fertilizers are not economically competitive. Many agents also were concerned that many farmers could not succeed with low-chemical methods because they lacked the necessary management skills. A few agents believed that yields and livestock health could not be maintained with low levels of chemical inputs.

Those agents who were sympathic toward maintaining the number of family farms were asked whether alternative agriculture, as defined above, could help in achieving that goal. Only four said that alternative agriculture practices might help maintain the number of farmers; the majority said that alternative agriculture could do very little to reverse the strong trends toward larger and fewer farms.

Although all but two agents agreed with the goal of strengthening rural communities, few believed that alternative agriculture could contribute much toward that goal. Many thought that rural communities could best be revitalized by encouraging rural value-added industries; others said that rural communities would have to adjust to a future of less dependence on agriculture.

Discussion and Conclusions

Minnesota county agricultural extension agents are diverse in their views and knowledge of the sustainable agriculture movement and their interactions with it. Despite that diversity, some general tendencies emerged from the interviews.

Most agents interviewed were broadly aware of the objectives and practices of alternative agriculture organizations, but remained skeptical about whether the changes these organizations advocated were feasible and needed. In 1992, only a few agents interacted regularly with sustainable agriculture groups, but many said that the sustainable agriculture movement played a valuable role in challenging the status quo.

Most believed strongly that the information from university and extension research was valuable because it was unbiased and scientific, and many valued it over information from other sources. Critics of the land-grant system charge that it has focussed on productivity over other aspects of sustainability, thus biasing the research (e.g., Berry, 1977; Flora, 1991; Strange, 1988). While non-profit groups and state sustainable agri-

Table 4. Barriers to meeting the goals of alternative agriculture through reduction of off-farm inputs and increased reliance on on-farm processes, as identified by county extension agents (n=19).

Barrier	No. Listing Barrier
Economic Constraints	
Lack of economically competitive on-farm alternatives to pesticides	8
Lack of economically competitive on-farm alternatives to commercial fertilizer	7
Economic risk of transition	3
Management/labor constraints	
Increased management skills necessary	6
Increased labor requirements	2
Narrow time windows	2
Management is better with specialization	1
Attitudes	
Farmer attitudes	6
Bankers/agribusiness create barriers	2
Social or economic peer pressure on farmers	1
Structural or Policy Constraints	
Cheap food policy; low crop prices	4
Lack of livestock in many operations	4
Large size of many farms	2
Agronomic Constraints	
Difficult to maintain yields and livestock health with low chemical inputs	2
Trade-off between reduced or no-till and need for pesticides	2
Other	3

culture agencies are encouraging farmers to design and run their own research, many agents were skeptical about the reliability of farmer-run research because it often is not carefully controlled. They also questioned whether it is in the best interests of the farmers to ask them to bear the expense and risk of their own experiments.

There was strong agreement with the broad economic and environmental goals of alternative agriculture, but many agents believed that those goals were being met, or could be met, by conventional agriculture. Most recognized some environmental problems in their county and were involved in addressing them, but few gave as high priority to environmental problems as to the problem of farm profitability.

A more fundamental difference between county extension agents and the sustainable agriculture movement in Minnesota and the Midwest concerns the place of social goals in agriculture. Two of the state's most active sustainable agriculture organizations, the Land Stewardship Project (1992a) and the Energy and Sustainable Agriculture Program of the Minnesota Department of Agriculture (1991) have social goals that include maintaining or increasing the number of family farms. One goal of the SARE program is "to strengthen the family farm system of agriculture, a system characterized by small and moderate-sized farms that are principally owner-operated" (U.S. Dept. of Agric., 1994). Although most of the agents I interviewed came from farming or rural backgrounds and expressed sympathy with the goal of maintaining the number of farms, almost all considered such a goal impossible or inappropriate. Most believed the current trends toward fewer and larger farms either was a natural economic process or was necessary to meet another social goal: cheap food. They tended to view the current trajectory in the structure of agriculture as value-free, while viewing the explicitly stated values of the sustainable agriculture movement as inappropriate. This tendency to accept the broad economic (profitability) and environmental goals of sustainable agriculture, while rejecting its social goals, was also found among Washington State University's agricultural faculty (Dunlap et al., 1992).

The results of this survey suggest both possibilities and barriers to increasing the role of county extension agents in the promotion of sustainable agriculture. County agents shared certain economic and environmental goals with advocates of sustainable agriculture, and many are open to, if not already involved in, some alternative agriculture practices. A hopeful sign for cooperation is the Minnesota Institute for Sustainable Agriculture, which is bringing together the University of Minnesota and several sustainable agriculture advocacy groups to improve collaboration on research and education on sustainable agriculture (Land Stewardship Project, 1992b). As Batie and Taylor (1991) have argued, progress can be made on shared goals, such as environmental goals, by focusing on desirable technologies that address those goals rather than on underlying belief systems.

However, fundamental differences in goals and world view are barriers to fruitful dialogue and collaboration between the agents and those who advocate a change in the current trajectory of agriculture. Agents who view information and research coming from the land-grant institutions as unbiased and more reliable than other sources are unlikely to value or promote alternative farmer-run research. Similarly, agents who reject the social goals of the sustainable agriculture movement are unlikely to look for or promote technologies that favor smaller-scale agriculture. The kinds of technological and structural changes needed to meet the broad environmental and economic goals that extension agents tend to support differ from those needed to meet the social goals of sustainable agriculture.

Thus, progress toward a sustainable agriculture that includes fundamental changes will require more than training in technical knowledge. That county agents expressed sympathy for the goal, if not the feasibility, of maintaining family farms suggests they are not opposed to an alternative to the current trajectory, but only lack a vision of possible alternatives. Differences in vision, although a difficulty, are less of a barrier to dialogue than are differences in values (Hamlin and Shepard, 1992). However, their values also may differ from those of sustainable agriculture advocates.

The SARE training projects and other attempts to involve extension institutions in sustainable agriculture must present a convincing case for an alternative vision of agriculture. Many agents remain unconvinced or unclear about that vision, while seeing no irresolvable problems with the current system and trends. Moreover, agricultural scientists tend to view the conventional system as objective or value-free (Curry-Roper, 1992) and to regard challenges to that system as inappropriately value-laden. This tendency must be changed before agents are likely to think seriously about alternative visions.

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UPCOMING EVENTS

September 13–14, "National Teleconference on Sustainable Communities," sponsored by the U.S. Department of Commerce, will be held; to locate a downlink, contact Sustainable Communities Teleconference, U.S. Department of Commerce, 14th and Constitution, Room 5222, Washington, D.C. 20230; 1-800-734-2235.

September 14–16, "Taking A Broader View," the annual meeting of the Society for Ecological Restoration, will be held in Seattle, WA; contact SER Conference Registration, 1207 Seminole Highway, Madison, WI 53711; (608) 262-9547.

September 16–17, New Jersey Organic Country Fair will be held in Pennington, N.J.; contact Julie Pace, Donna Batcho, Northeast Organic Farming Association, (609) 737-6848.

September 17–19, "Alligators, Organics & You: Replacing Pesticides and Advancing Alternatives," the 1995 PAN North America Conference, will be held in Menlo Park, CA; contact Brenda Willoughby or Wendy Anderson at PANNA, (415) 541-9140; e-mail panna@panna.org

September 18–29, a technical short course on "Agricultural Ecology" will be held at the University of Florida, Gainesville; contact the University, International Programs/FANR, Training Unit, P.O. Box 110329, Gainesville, FL 32611-0329; (904) 392-1965; e-mail ITD@GNV.IFAS.UFL.EDU

September 19–21, "Biodiversity in Agriculture" will be held in Beijing, China; contact Sandra Bukkens, Organizing Secretariat, Istituto Nazionale della Nutrizione, Via Ardeatina, 546, 00178 Rome, Italy; phone 39-6-50-32-421; e-mail Giampietro@in8800.ingrm.it

September 21–23, "Therapeutic Landscapes: Designing Gardens for Health and Healing," and optional garden tour, will be held at the Cleveland Botanical Garden, OH; contact Cleveland Botanical Garden, 11030 East Blvd., Cleveland, OH 44106; (216) 721-1600.

September 22–29, "Introduction to Biodynamics for Beginners in Agriculture;" and **September 29–30,** "Fall Harvest Organic-Biodynamic Gardening & Food Preserving Workshop," will be held at Michael Fields Agricultural Institute, East Troy, WI; contact MFAI, W2493 County Road ES, East Troy, WI 53120; (414) 642-3303.

September 30, Second Annual Country Living Field Day will be held in Carroll County, OH; contact Ohio State University Extension, (216) 627-4310.

October 5–8, "Gardens: Pathways to Community," the annual conference of the American Community Gardening Association, will be held in Portland, OR; contact Leslie Pohl-Kosbau, Portland Parks and Recreation Community Gardens, 6437 S.E. Division St., Portland, OR 97206; (503) 823-1612.

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Västgötmodellen: Sweden's sustainable alternative for swine production

Mark S. Honeyman

Abstract. *In a harsh, northern climate and under restrictive animal welfare laws and a strict ban on the use of subtherapeutic antibiotics, Swedish pig farmers have developed a management-intensive system of pig production that relies on straw, the animals' natural behavior, group housing dynamics, and keen husbandry skills. The system is very efficient, with excellent pig reproduction and growth performance. The housing is simple and versatile. Called "Västgötmodellen" after the region in western Sweden where it was developed by farmers during the 1980s, the system now is successfully used on approximately 100 farms in Sweden. The system is specific to producing feeder or weaner pigs of 25 to 30 kg for feeding in more conventional European-style finishing units. Västgötmodellen may represent an agricultural system that is well adapted and economically competitive on modest-sized farms but not well suited for very large farms.*

Key words: sustainable livestock systems, livestock housing, animal behavior

Introduction

Animal agriculture is a fundamental segment of sustainable agriculture (Baker et al., 1990). There are inherent advantages in linking crop and livestock enterprises on the same farm or in the region where feed is produced. This linkage allows for nutrient cycling and other environmental advantages. From a socioeconomic viewpoint, livestock are an important value-added agricultural product, generating jobs and rural economic activity.

Swine production is an important type of livestock production in some regions, where it may make a critical contribution to sustainable agriculture. Sustainable swine production is a combination of production techniques that enhance profit and improve the area's environmental and socioeconomic conditions (Honeyman, 1991).

A system of swine production that may fit this definition is used in Sweden. It is called the Västgötmodellen system, after the Västgötland region in western Sweden where it was developed by farmers, largely in response to Sweden's ban on subtherapeutic use of antibiotics for livestock in 1986 and the passage of strict animal welfare laws in 1988. The system is efficient and competitive with conventional confinement systems. Feeder or weaner pigs (25 to 30 kg) are produced for subsequent feeding to slaughter weight in more traditional European-style finishing units. Västgötmodellen is interesting because it relies on the natural behavior of the pig and good husbandry skills by the farmer. The system has possible applications in other parts of the world and has lessons for everyone interested in sustainable agriculture and swine production. Additionally, Västgötmodellen may represent a rare instance of a size-specific technology system developed by farmers for diversified, modest-sized farms.

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Development

Fig. 1 shows the two variations of the Västgötmodellen system of swine production. Type 1, also called the Ljungström system, is the more common, and is successfully used on about 100 Swedish swine farms (B. Algers, Swedish Univ. of Agric. Sciences, Skara, personal communication, 1994). It is named after Gunnar Ljungström, an enterprising farmer who began the system in the 1980s in response to a space shortage and a disease problem on his farm near Skara. He put sows and litters for the lactation period in a machine shed with a large amount of straw. The sows weaned more pigs then his penned sows, after which he began refining the new system.

A neighboring farmer, Connie Thorstensson, took the approach one step further and developed Type 2. He farrowed the sows in temporary free-stall cubicles in the deep-bedded room. After two weeks, he removed the cubicles and began group lactation. The Type 2 Västgötmodellen is successfully practiced on fewer than five Swedish farms, probably because it represents a greater variation from conventional production and requires a more extreme management approach. From a U.S. perspective, the Type 2 (Thorstensson) variation is intriguing because it mimics outdoor pasture farrowing systems, where sows are allowed to choose their farrowing hut (cubicle) freely and are allowed free access to feed and water. However, being indoors allows the producer to capture the advantages of outdoor farrowing year-round while eliminating problems of environmental extremes (cold, heat, rain, wind, and mud) and predators (coyotes, wild dogs, and birds

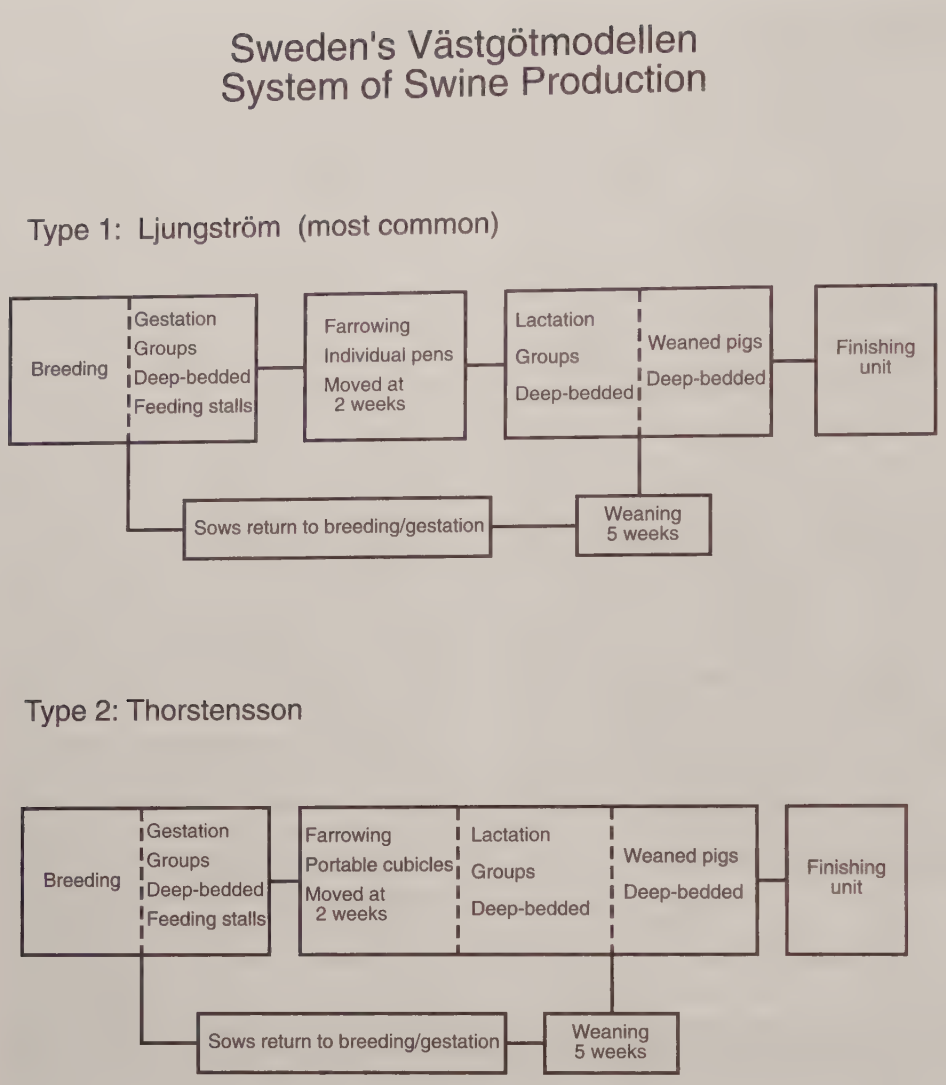

Figure 1. Sweden's Västgötmodellen System of Swine Production.

of prey). In essence, Type 2 Västgötmodellen brings pasture farrowing indoors.

The Västgötmodellen system developed in a region that includes a small group of respected animal ethologists at the Swedish University of Agricultural Sciences in Skara who specialize in livestock. This group conducted intensive studies on the natural behavior of domestic pigs in a free range "pig park" beginning in 1983 (Jensen, 1986; Jensen et al., 1987). The scientists interact considerably with the area's farmers and no doubt helped to get animal behavior science or ethology included in the design of Västgötmodellen.

The strong pig cooperative in this region also is an important element. The cooperative owns the slaughter plant and controls breeding stock. Cooperative advisors routinely visit swine farms and provide advisory and recordkeeping services. These advisors helped shape Västgötmodellen and spread it throughout the region.

Description

The Västgötmodellen system has been documented primarily by Algers (1991) and Halverson (1991a,b), and in the U.S. popular press by Halverson (1994) and Bowman (1993). As shown in Fig. 1, it uses group housing of sows in deep straw during breeding and gestation. During gestation the sows are fed daily in individual feeding stalls with rear gates that the farmer closes after the sows have entered the stalls. The stalls also have front access gates that open into the feeding alley. The stalls offer the advantages of individual stalls: individual feeding, control of the sow for vaccinations and artificial insemination, and easy sorting of sows. The group housing helps stimulate estrus and reduce stress on the sows by allowing them to live in groups, which they prefer. Fighting is minimized by using feeding stalls and introducing new sows to the groups at optimum times, such as at farrowing. Conception rates are high, sow longevity is long, and sow mortality and culling rates are low.

The producer controls the swine herd and closely keeps exact records of breeding. This is a key to successful Västgötmodellen. As parturition approaches, the pregnant sows are moved to individual farrowing pens, and pregnant gilts are added to the group. These gilts have been bred to coincide with a given farrowing group of sows.

The farrowing pens are large and bedded with straw. Straw (oat, wheat, or barley) of high quality is a major system input. About 1,400 to 2,100 kg of straw is required per sow per year. Sow manure is removed twice daily. Most new farrowing pens have a slatted dung area with a scraper underneath. A heat lamp is provided in the creep area for warmth and to attract the piglets away from the sow. Swedish law prohibits farrowing crates.

Two weeks after farrowing, the sows and litters are moved to a lactation room. The move is done gradually; only two or three sows and litters are moved, after which there is a wait of several hours before more sows and litters are moved. This allows the sows and their piglets to reestablish their bonds before more sows and piglets are added to the group. The sow-pig bonding is important for successful group lactation. There are 6 to 16 sows in a group, with 8 to 10 optimum. According to the Swedish farmers (Halverson, 1991a,b), larger groups usually are unsuccessful because of fighting and social disorder. Smaller groups are considered economically impractical (Halverson, 1991a,b).

The Type 2 (Thorstensson) variation eliminates the farrowing pens. When the pregnant sows are removed from the gestation area, they go directly to the lactation room as a group. Temporary farrowing cubicles are set up in the lactation room for the

sows to farrow. The cubicles are removed when the piglets are about two weeks old (Fig. 1).

The lactation rooms are large and quiet. They are approximately square, with a solid concrete floor, a large access door for delivering straw (usually large round bales) and removing manure, automatic waterers, and a raised feeding platform (1.25 m wide, 40 cm high). No supplemental heat is used in the rooms. Animal heat, manure pack heat and the straw bedding provide a good environment for the pigs. This remarkably spacious and simple approach to swine housing is in sharp contrast to elaborate U.S. farrowing and nursery confinement facilities.

While the piglets are from two to five weeks of age, they and the sows occupy the lactation rooms. During this time the sows are allowed free access to feed and water and the piglets begin consuming feed, often with the sows. Piglet mortality is low, about 6% (Halverson, 1991a). Straw is added often, usually daily, when the pigs are inspected. Within the group the piglets' age varies by only 3 to 5 days. At nursing, the sows position themselves around the room. Some cross-suckling occurs, but it is not a problem because of uniform pig age and size. The quiet rooms allow for good sow-pig communication (Algers, 1993). Many producers grind off the piglets' needle teeth to minimize fighting injuries. Sow lactation problems (e.g., mastitis, metritis and agalactia) are negligible, probably because the sow has plenty of exercise and consumes some straw as a fiber source, and because stress is low (Algers, 1993; Algers, personal communication, 1994). The sow's feed intake and milk output are high, which results in rapid piglet growth (Algers, 1992).

The piglets are weaned at five or six weeks of age by moving the sows back to the breeding/gestation area. Weaning stress is minimized by removing the sows rather than the piglets. The piglets are fed in the lactation rooms as a group until 25 to 30 kg or 14 weeks of age, when they are moved to a finishing unit, which is usually at a different location.

The U.S. and Swedish systems differ markedly, but both can achieve high production levels. Table 1 shows a simple comparison of Västgötmodellen and typical U.S. confinement production systems. The U.S. systems rely on mechanization, automation, confinement, and antibiotics. The Swedish Västgötmodellen system, however, relies more on animal behavior, husbandry, and minimizing stress on the pigs.

Performance

The Västgötmodellen system seems to be performing well on many farms. Most producers report they produce 20 to 24 pigs per sow per year with a five-week weaning age. These statistics are reliable because of the recordkeeping system of the producers' cooperative. Halverson (1991a,b) reported an average of 21.5 pigs per sow per year for the Type 2 (Thorstensson) system, an excellent level. In comparison, the 1992 Iowa Swine Enterprise Records reported an average of 19.4 pigs per sow per year for the most profitable feeder pig producers and an average of 17.2 pigs per sow per year for all producers (Stevermer, 1993). There was no relation between size of farm and profitability (Stevermer, 1993). The Pork Industry Handbook (Mayrose et al., 1991) describes a production level of over 20 pigs per sow per year as excellent.

Exact economic comparisons are difficult, however, because production can be calculated several different ways. In Sweden, the producers buy replacement gilts at either 30 kg or as pregnant gilts. In the U.S., many producers raise their own replacement gilts. The time at which gilts are considered part of the breeding herd, promptness in selling unproductive sows, and age at weaning are additional variables in determining pigs per sow per year.

Sow death loss (mortality) is low in the Västgötmodellen system, probably less than 1% (exact records not available). The Iowa Swine Enterprise Records Summary reports an average sow death loss of about 5% for Iowa feeder pig producers (Stevermer, 1993). A combination of natural service and artificial insemination is used on most farms. Also, in Västgötmodellen, the sow culling rate is low and sow longevity is longer than for typical U.S. production standards. Most producers keep sows

Table 1. A comparison of Swedish Västgötmodellen and conventional U.S. confinement pig raising systems.

	Sweden	U.S.
Subtherapeutic antibiotics	no	yes
Swine buildings	simple, easily modified	specialized, single purpose
Potential production level	high	high
Equipment	almost none	extensive
Gestation	group	individual crates
Farrowing	individual pen with straw or free-choice boxes	farrowing crates
Lactation	group with straw	farrowing crates
Nursery	large groups in pen with straw	controlled environment, small group decks
Weaning	sows removed, pigs stay	pigs moved to hot nursery
Tail docking	no	yes
Cross-fostering	yes	yes
Floors	solid concrete with straw	slats and manure pits
Manure	solid	liquid
Replacement gilts	buy as gilts or bred gilts	raise or buy as gilts
Finishing pen size	small	large
Finishing group size	8–15 pigs	25–35 pigs
Finishing pen floor	partial slat/straw	total slat, no straw
Bedding (straw)	yes	no
Feed	liquid	dry
Pig behavior	important	not important

through the sixth parity, and one reported keeping sows through the tenth parity. Overall reproductive performance of the Västgötmodellen system was very good. Pig health seemed excellent in this system, which was designed to be compatible with the animal's innate behaviors and to minimize stress.

Without the subtherapeutic use of antibiotics, management of the pigs becomes an important factor in successful production. Producers use strict batch production and all-in, all-out techniques, with no commingling of piglets from different groups. A narrow farrowing interval and precise breeding management insure that the piglets within a group usually differ in age by no more than five days. Odd litters born out of sequence are housed in separate overflow areas and kept separate until they are moved to the finishing unit. The "soft" environment of straw, established groups, loose-housing, quiet insulated rooms, and good ventilation, plus keen management, reduces stress and health problems.

Most Swedish pig farmers using Västgötmodellen observe their pigs closely, viewing every pig at least once a day. One farm couple visit the farrowing area five times per day! These producers enjoy pigs very much and have attained excellent results using the Thorstensson system. Clearly there is a strong positive pig-human bond on their farm. The pigs are tame and friendly. Where humans handle pigs in a positive manner, growth and reproduction are enhanced. Sows that are relaxed around human researchers tended to have higher reproductive performance (Hemsworth et al., 1981). Västgötmodellen would be viewed positively by most people concerned about livestock care and welfare.

In the Västgötmodellen system, management is a key to success. The management requires close attention to detail, an understanding of pigs and their behavior, and consistency from day to day and from group to group. Precise breeding management is critical to ensure the narrow farrowing interval that allows for successful group lactation.

Implications

Västgötmodellen is an example of a farmer-developed, management-intensive alternative swine production system. It was developed in response to public concerns and laws related to subtherapeutic antibiotic use and livestock welfare. Västgötmodellen is an excellent example of creative solutions brought together by farmers into a system that is equal or superior to conventional systems. This process testifies to the remarkable creative resources of independent farmers and farm families in responding to the forces of change. As U.S. swine production becomes more industrialized and less diverse, the loss of independent farmers and their creative energy and quick ability to address change may become a great problem. Västgötmodellen may have application in the U.S., with some modifications for a more severe continental climate in the Midwest. Alternative sources of bedding also may be explored, such as corn stalks or newspapers. Västgötmodellen may be a size-specific system that is not well suited for large operations. This is unusual among most farm technologies, but may be characteristic of management-intensive systems.

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UPCOMING EVENTS
(continued from page 128)

October 10–11, "The Next Generation of Legal, Regulatory and Marketing Issues Facing the Organic Products Industry" will be held Oakland, CA; contact Organic Farming Research Foundation, P.O. Box 440, Santa Cruz, CA 95061; (408) 426-6606.

November 15–17, "Environmental Enhancement Through Agriculture," organized by Tufts University, Center for Agriculture, Food, and Environment; American Farmland Trust; and Henry A. Wallace Institute for Alternative Agriculture, will be held in Boston, MA; contact William Lockeretz, School of Nutrition, Tufts University, Medford, MA 02155; (617) 627-3233; e-mail wlockeretz @infonet.tufts.edu

Transition from conventional to alternative agriculture in Pakistan: The role of green manures in substituting for inorganic N fertilizers in a rice-wheat farming system

Tahir Hussain, Ghulam Jilani, James F. Parr, and Riaz Ahmad

Abstract. *Nitrogen, a vitally important plant nutrient, is subject to various losses that affect its efficiency. We tested prilled urea (PU), urea supergranules (USG), green manures (GM) and farmyard manure (FYM) in a rice-wheat cropping system to determine which were the most efficient and economical N sources. The maximum rice growth, yield and N-uptake occurred with USG and with GM (*Sesbania rostrata*) plus PU. Incorporation of GM saved 60 kg N/ha. On the following wheat crop, GM (*S. aculeata*) plus PU and FYM plus PU had the highest residual effect on the number of tillers per m^2, and straw and grain yield. An increase in N recovery efficiency occurred with combined use of PU and organic/green manures compared with PU alone. In areas where USG is costly or unavailable and FYM is scarce, green manures can be a cheap N source that allows small-scale farmers to get sustainable yields in a rice-wheat rotation.*

Key words: rice, wheat, farmyard manure, green manure, *Sesbania*, nitrogen fertilizer

Introduction

Pakistan consists of arid and semiarid regions where annual rainfall ranges from 90 to 1000 mm, with very hot summers. The future of Pakistan depends on agriculture. About 40% of its land (32 million ha) is under cultivation, and about 40% of its foreign exchange comes from agriculture. Agriculture also provides employment for the 75% of the country's labor force who work on its 4 million farms and in agriculturally related industries. Moreover, agriculture provides raw materials for major textile and sugar refining industries and smaller industries throughout the country.

Although crop yields and productivity have increased because of increased inputs, agricultural production is not keeping pace with population growth, which is over 3% per year. Therefore, Pakistan depends on imports of food grains and edible oil. Much of the required increased food production must come from higher crop yields; however, yields in Pakistan are among the lowest in the world.

In most countries that grow rice (*Oryza sativa*), lowland rice culture predominates. In this system, the land either is prepared wet by puddling the field or is prepared dry, but with water always held in the field. Nitrogen in flooded soils is subject to ammonia volatilization, denitrification, runoff and leaching, all of which contribute to low N use efficiency by rice. Most soils in arid and semiarid regions of South and Southeast Asia are low in organic matter, and because of low rainfall and high temperature are also deficient in N. Therefore, the soil N is supplemented with chemical fertilizers to meet the crop's N requirement.

Application of fertilizer N to rice can increase yields greatly, but it is costly because of low N use efficiency in flooded soils. Recovery of N by rice ranges from 10% to 60%, and typically is 30% to 40% (DeDatta, 1981). To maintain high production, it is important to achieve high use efficiency of available chemical fertilizers through proper application methods and by combining them with organic manures. The combination of synthetic N fertilizer and organic manures increases N use efficiency by crops and helps to reduce the amount of chemical fertilizer needed (Khind et al., 1982).

The supply of farmyard manure (FYM) and green manure (GM) is limited because of more intensive cropping and farm mechanization. Green manuring may be a feasible substitute for some fertilizer N. Sesbania (*Sesbania* spp.) is widely used as a green manure for rice. It contains 3% N, which corresponds to about 80 to 120 kg N/ha. In areas where N fertilizers are expensive, green manure may be satisfactory as an alternative or complementary N source for rice (Mamaril et al., 1986).

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It may be economically feasible to increase rice production through integrated nutrient management using a combination of mineral and organic fertilizers. Because of the high cost of N fertilizer and contamination of groundwater by nitrate from excessive use of N fertilizers (Glendining and Powlson, 1990) we evaluated the effects of combined use of organic and inorganic N fertilizers on the yield and profitability of irrigated lowland rice.

Materials and Methods

A three-year study was begun in 1987 to determine the extent to which including green manure (GM) in a rice-wheat (*Triticum aestivum*) rotation can substitute for synthetic N fertilizer. The soil was a sandy clay loam (pH: 7.9; EC: 1.2 dS/m; total N: 0.43 g/kg; available P: 8.7 mg/kg; organic C: 4.8 g/kg; CEC: 9.7 $cmol^{(+)}/kg$). The following treatments were applied in a randomized complete block design with three replicates:

T_1 = Control (no nitrogen)
T_2 = Urea supergranule (USG) alone
T_3 = Prilled urea (PU) alone in 2 splits (2/3 at transplanting, 1/3 at panicle initiation)
T_4 = *Sesbania aculeata* (GM) + PU (50% N from each)
T_5 = *Sesbania rostrata* (GM) + PU (50% N from each)
T_6 = Farmyard manure (FYM) + PU (50% N from each)

The total N rate was 87 kg/ha in all treatments; P and K were applied at the recommended rates of 18 kg/ha and 40 kg/ha, respectively. One urea supergranule weighing 3.0 g was placed manually 10 cm deep in the center of every 4 rice plants in the USG-treated plots. Green manures were grown *in situ* in the respective plots for 35 days and incorporated before rice (cv. KS-282) was transplanted. In plots where green manure supplied less than 50% of the total N rate, more GM biomass was added from the plots that had accumulated more than 50% of the N rate. After rice was harvested, wheat (cv. Pak-81) was grown as a rabi (October to April) crop and the residual effect of organic sources was determined. N, P and K were applied to wheat at the recommended rates of 150, 20, and 50 kg/ha, respectively, in each treatment.

For the next two years, the experiment was repeated with the same treatments in the same layout. However, the rate of N fertilizer on rice was raised to 116 kg/ha. During these three years, we recorded data on crop growth and yield, and assessed the economic returns for each treatment. We used analysis of variance on the cumulative three-year data to determine significant differences according to the methods given Steel and Torrie (1986). The comparison of means was tested at 5% probability level using Duncan's Multiple Range Test (Duncan, 1955). The Nitrogen Recovery Efficiency (NRE) was calculated using the following formula:

NRE (%) = (N uptake in fertilized plot – N uptake in control) × 100/(N applied)

Results and Discussion

Nitrogen contribution from green manuring

A maximum N level of 91 kg/ha was produced by *S. aculeata* because of its greater biomass production (Table 1). *S. rostrata* had a higher N content than *S. aculeata* but produced less total N because it was less adapted to the semiarid climate of Pakistan than to its native environment in the Philippines. Nevertheless, both species have the potential to provide at least half of the N required by rice. Meelu and Morris (1987) and Kolar and Greval (1988) reported that, assuming 100% efficiency, incorporation of green manure can result in a saving of 60 to 90 kg N/ha in rice.

Growth and yield of rice

Averaged over three years, USG was significantly higher in number of tillers per m^2 than PU with either *S. rostrata* or *S. aculeata* GM or with FYM (Table 2). FYM and both GM species with PU were superior to PU alone. Jha et al. (1980) also found that incorporating 5 to 10 t/ha of *Ipomoea carnea* GM into the soil 3 to 5 days before puddling, with or without the application of fertilizer N, increased the number of ear-bearing tillers per m^2.

Paddy rice yield (Table 3) was highest with USG and was statistically greater than the yields with GM or FYM. The lowest yield besides the control was with PU alone, which clearly shows the extra benefit of green or organic manuring, even though a constant amount of N was applied in all treatments. N fertilizer alone is subject to loss through ammonia volatilization, denitrification, and leaching under flooded conditions. Khind et al. (1982) also reported increased yields from 60 kg N/ha with *S. aculeata*, cowpea (*Vigna unguiculata*) or guar (*Cyamopsis tetragonoloba*) green manures. Therefore, N fertilizer use efficiency for rice can be enhanced by green manuring with sesbania, which allows the total amount of N applied to be lowered. Similar results were reported by Mian et al. (1988).

Treatment effects on straw yield were similar to paddy yield (Table 4). The likely explanation here is that all the green manures and FYM were combined with an equal quantity of urea N. Urea is a quick source of available N, whereas the N in FYM or GM only becomes available to the plants after mineralization. This resulted in smaller amounts of fertilizer and mineralized N being lost from the soil-root zone, and greater recovery of the organic N by the crop. Hussain et al. (1988) reported similar results with the combined use of organic and inorganic N fertilizer in lowland rice. This suggests that, where N fertilizer is costly or unavailable and FYM also is scarce, small-scale farmers can use green manures for agronomic and economic advantages to obtain sustainable yields in a rice-wheat rotation.

Nitrogen uptake by rice grain and straw

Nitrogen uptake by grain and straw varied among treatments (Table 5). USG gave the highest values, which were statistically superior to all other treatments. This was

Table 1. Nitrogen content of sesbania species as green manures after 35 days of growth.

	1987		1988		1989		Average	
Green manure crop	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha
S. aculeata	2.7	60	3.2	103	3.4	110	3.1	91
S. rostrata	2.4	29	3.5	77	3.6	82	3.2	63

Table 2. Effect of combined use of N fertilizer and organic manures on number of rice tillers per m^2.

Treatment	Rice Tillers per m^2			
	1987	1988	1989	Average
1. Control	239gh[1]	212h	221h	224.4D
2. USG	339b	397a	333bc	356.7A
3. PU	265fg	268efg	295cdef	276.3C
4. PU + *S. aculeata*	298cdef	330bc	306bcde	311.5B
5. PU + *S. rostrata*	306bcde	326bcd	289def	307.6B
6. PU + FYM	260fg	341b	290def	297.5B
Average	285B	313A	289B	

[1] Differences between values of treatment/year combinations, treatment means, or yearly means followed by the same letter are not statistically significant ($p<.05$).

Table 3. Effect of combined use of N fertilizer and organic manures on paddy yield (t/ha).

Treatment	Paddy Yield (t/ha)			
	1987	1988	1989	Average
1. Control	2.68f[1]	3.27e	1.96g	2.64E
2. USG	5.70a	5.66a	5.61a	5.66A
3. PU	5.29ab	4.50d	4.28d	4.69D
4. PU + *S. aculeata*	5.19ab	5.20ab	4.62cd	5.00BC
5. PU + *S. rostrata*	5.55a	5.58a	4.60cd	5.25B
6. PU + FYM	5.14abc	4.73bcd	4.72bcd	4.87CD
Average	4.93A	4.83A	4.30A	

[1] Differences between values of treatment/year combinations, treatment means, or yearly means followed by the same letter are not statistically significant ($p<.05$).

Table 4. Effect of combined use of N fertilizer and organic manures on rice and wheat straw yields (average of three years, t/ha).

Treatment	Straw Yield (t/ha)	
	Rice	Wheat
1. Control	4.28d[1]	3.92c
2. USG	7.70a	4.55b
3. PU	6.43c	3.87c
4. PU + *S. aculeata*	6.62c	5.13a
5. PU + *S. rostrata*	6.98b	4.37b
6. PU + FYM	6.59c	4.63b

[1] Within a column, differences between values followed by the same letter are not statistically significant ($p<.05$).

due to the controlled release of N from USG, which was deeply placed. The next highest values were from PU with either GM or FYM, all of which were statistically similar. PU alone resulted in the lowest N uptake among fertilizer treatments.

Residual effect of green manuring on wheat

Residual N availability with PU was negligible, but other treatments affected the number of tillers per m^2 (Table 6). The highest values were obtained with FYM and *S. aculeata*, followed by *S. rostrata* and USG. There was little difference among organic sources, but all these resulted in significantly more tillers per m^2 than PU alone. These results are similar to those of Bhardwaj et al. (1981).

Wheat grain yield (Table 7) and wheat straw yield (Table 4) showed similar residual effects. Nevertheless, FYM and GM clearly are superior to PU alone, and give a benefit to both crops in a rice-wheat cropping system. Mahapatra and Sharma (1988) concluded that combined use of organic and inorganic fertilizers in rice significantly affected the succeeding wheat grain yield. Similar results were obtained by Tiwari et al. (1980) who found that rice yields with GM (sesbania) plus fertilizer N at 40 kg/ha were equivalent to those with fertilizer N at 120 kg/ha, and that wheat grain yields in the following season increased because of the residual effect of the GM.

Nitrogen recovery efficiency

Application of USG gave the highest NRE (Table 8). The next best values were obtained with PU combined with GM or FYM. These results again show the potential benefit of including local green manure species in rice-based cropping systems.

Economics of green manure

The only expenditure we considered was for N from various sources, since other expenses were constant across treatments. For both the rice and wheat crops, we compared cost and net income with GM or PU. Although GM is more expensive than N fertilizer (PU) alone, it also had higher profits.

Table 9 shows average annual costs for applying N to rice and wheat under each treatment. Costs were higher for USG because of its higher price (about 30% more than PU) and the labor needed for placement. FYM also costs more because of its short supply and high transportation charges. The cost of green manuring also was higher than for PU alone, but slightly lower than with USG or FYM. Gross revenue from rice and wheat was highest with USG. This is a standard treatment in rice that has high N use efficiency because its slow release minimizes N losses. However, green and farmyard

Table 5. Effect of combined use of N fertilizer and organic manures on N uptake by rice grain and straw (average of three years, kg/ha).

Treatment	N Uptake (kg/ha)	
	Grain	Straw
1. Control	31.22d[1]	25.73d
2. USG	71.48a	49.91a
3. PU	57.07c	39.11c
4. PU + *S. aculeata*	63.64b	41.85bc
5. PU + *S. rostrata*	64.31b	42.39b
6. PU + FYM	60.67bc	43.79b

[1] Within a column, differences between values followed by the same letter are not statistically significant ($p<.05$)

Table 6. Effect of combined use of N fertilizer and organic manures on number tillers of wheat per m^2.

Treatment	Wheat Tillers per m^2			
	1987	1988	1989	Average
1. Control	199	185	194	193C[1]
2. USG	217	233	240	230AB
3. PU	209	224	232	222B
4. PU + *S. aculeata*	231	238	238	236A
5. PU + *S. rostrata*	213	236	244	231AB
6. PU + FYM	242	227	248	239A
Average	219B	224B	233A	

[1] No differences between values for treatment/year combinations are significant. Differences between treatment averages or yearly averages followed by the same letter are not statistically significant ($p<.05$).

Table 7. Effect of combined use of N fertilizer and organic manures on wheat grain yield (t/ha).

Treatment	Wheat Grain Yield (t/ha)			
	1987	1988	1989	Average
1. Control	2.45	2.19	2.29	2.31C
2. USG	2.87	2.99	2.90	2.92AB
3. PU	2.70	3.05	2.60	2.78B
4. PU + *S. aculeata*	2.74	3.45	3.11	3.10A
5. PU + *S. rostrata*	2.76	3.16	2.85	2.93AB
6. PU + FYM	2.92	3.12	2.92	2.99AB
Average	2.74B[1]	2.99A	2.78B	

[1] No differences between values for treatment/year combinations are statistically significant. Differences between treatment averages or yearly averages followed by the same letter are not statistically significant ($p<.05$).

manures also gave better results than PU alone.

All N applications to rice gave a profit over the control treatment. The lowest profit was obtained with PU alone, the highest with USG. However, green manuring also was considerably more profitable than PU alone (US $69 to $78/ha). *S. aculeata*, the local species, was somewhat better than *S. rostrata*, a tropical species, under our conditions.

Table 8. Nitrogen recovery efficiency (%) of green manures and mineral fertilizers for rice over control (average of three years).

Treatment	NRE(%)	
	Paddy	Straw
1. Control	—	—
2. USG	37.3	22.8
3. PU	24.6	12.3
4. PU + *S. aculeata*	27.9	14.7
5. PU + *S. rostrata*	31.0	16.1
6. PU + FYM	24.3	17.4

Conclusions

In the rice-wheat cropping system, sesbania green manure can supply from 60 to 90 kg N/ha after 35 days of growth preceeding rice. This N can substitute for about 50% to 75% of the rice's N requirement. If half the N (58 kg/ha) is supplied by green manure and the other half by prilled urea, both crops' yields and net returns are higher than with PU alone. The combined use of organic and chemical N fertilizers gives results comparable to those obtained with USG, whose N use efficiency is much higher than that of PU.

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Table 9. Economics of transition for soil fertility enhancement under rice-wheat cropping (Rupees ha^{-1} yr^{-1}).

	Control	USG	PU	PU + *S. aculeata*	PU + *S. rostrata*	PU+FYM
Cost of N (Rs./ha)						
1. 116 kg N from USG, @ Rs.8.45/kg N	—	980	—	—	—	—
2. 35 hr labor to place USG @ Rs. 5.00/hr	—	175	—	—	—	—
3. 116 kg N from PU, @ Rs.6.50/kg N	—	—	754	—	—	—
4. 7 hr labor to broadcast PU @ Rs. 5.00/hr.	—	—	35	—	—	—
5. 50 kg GM seed @ Rs.5.50/kg	—	—	—	275	275	—
6. Labor for sowing, harvesting & spreading GM	—	—	—	140	140	—
7. GM rotatation charges @ 375/ha	—	—	—	375	375	—
8. 15 t FYM @ Rs. 50/t	—	—	—	—	—	750
9. Labor to broadcast FYM	—	—	—	—	—	105
10. 58 kg N from PU in GM/FYM treatment @ Rs. 6.50/kg N	—	—	—	377	377	377
11. 3 hr labor to broadcast PU in GM/FYM treatment @ Rs. 5.00/hr	—	—	—	15	15	15
12. 150 kg N from PU for wheat @ Rs. 6.50/kg N	975	975	975	975	975	975
13. 7 hr labor to broadcast PU @ Rs. 5.00/hr	35	35	35	35	35	35
TOTAL EXPENDITURE FOR N	1,010	2,165	1,799	2,192	2,192	2,257
Gross Revenue						
1. Paddy @ Rs. 2.00/kg	5,280	11,320	9,380	10,000	10,500	9,740
2. Rice straw @ Rs. 0.15/kg	642	1,155	964	993	1,047	988
3. Wheat grain @ Rs. 2.50/kg	5,775	7,300	6,950	7,750	7,325	7,475
4. Wheat straw @ Rs. 0.40/kg	1,568	1,820	1,548	2,052	1,748	1,852
TOTAL GROSS REVENUE	13,265	21,595	18,842	20,795	20,620	20,055
NET INCOME	12,255	19,430	17,043	18,603	18,428	17,798
Profit over control from using N	—	7,175	4,788	6,348	6,173	5,543
Profit over PU from USG or GM/FYM						
Rs.	—	2,386	—	1,560	1,385	755
US $	—	119	—	78	69	38

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COMMENTARY

Weed science in sustainable agriculture

Robert L. Zimdahl

Abstract. *Five thoughts about the role and future of weed science in agriculture are analyzed. Much about the tools, techniques, and achievements of weed science should be lauded. Its achievements in basic science and its worldwide contributions to agricultural production and productivity are incontestable. The discipline has been based primarily on chemical technology, and the weed science community has been shaped by the available technology and by the purposes of its members. New, sustainable weed management systems will rely on knowledge derived from answers to new questions about weed-crop relationships and management techniques. As weed scientists develop better management systems, they will need to find better words to describe what they do and why it is important.*

Key words: herbicides, weed management, population biology, ecology

Introduction

Many voices are encouraging farmers to consider and adopt low-cost, resource conserving, environmentally sound farming methods. This journal has pointed out that "serious questions are being raised about modern farming's dependence on nonrenewable production inputs, its adverse impact on soil and water and other natural resources, and its growing dependence on agricultural chemicals" (Youngberg, 1986). The basic question is: How should farmers farm? "From time immemorial," Wojcik (1989, p. x) tells us, "there has really been only one answer. Farmers should farm so they can farm again tomorrow."

Weed science, a subdiscipline of agriculture, hears the same voices and questions, and weed scientists are struggling to find acceptable answers. The struggle arises in part because the science's creation coincided with the development of herbicides that have dominated thought and action. There also is a fundamental belief that controlling weeds is essential to agricultural productivity if food is to be produced for everyone in sustainable systems.

Producing enough food locally and worldwide is an egalitarian, agricultural ideal shared by many scientists and institutions. The ideal, often cited as the creed of the U.S. land-grant university system, often is presented in the words of the King of Brobdingnag to Captain Lemuel Gulliver: "He gave it for his opinion, that whoever could make two ears of corn or two blades of grass to grow upon a spot of ground where only one grew before, would deserve better of mankind, and do more essential service to his country than the whole race of politicians put together" (Swift, 1726 [1972], p. 129).

The King's words are used to justify the mission of land-grant agricultural colleges, but Browne et al. (1992) ask if that mission might not be outdated in high-income societies that have almost no need for more food but where environmental quality is important. They suggest that agricultural research should shift direction toward the highest quality consumer goods, including environmental amenities, and more nutritious food.

Weed scientists have accepted and contributed to the land-grant mission. They have not examined the fundamental assumptions of the mission or those that drive the science. I discussed some of these assumptions (Zimdahl, 1991) and was guided then and now by my feeling that weed science is good but can be better. Weed scientists do not often discuss the "goodness" of their science because they know that producing food is a worthy goal. They assume that nothing is wrong with their science, its goal of increasing production, or the means of achieving it. In this paper I briefly explore five suggestions about the nature of weed science and its future.

1. Within the land-grant system weed science has been an economically dominated, technical specialty divorced from its basic supporting sciences.
2. Weed science might more properly be called "herbicide science"; reliance on herbicides has become too great (Thill et al., 1991; Wyse, 1992).
3. Weed management will benefit as truly integrated, sustainable weed management systems are developed; that can be done best by studying weed biology and the ecological principles that support sustainable management systems.
4. Increased emphasis on population biology and ecology will be good for weed science.
5. Weed science will benefit as an ethical foundation is developed and debated.

Weed Science and Supporting Sciences

Agricultural science has been looked down on by older disciplines as too practical and applied. Agriculture widened the gap by creating its own disciplines rather than working within the established disciplines of botany and zoology (Mayer and Mayer, 1974; Danbom, 1992). Weed science, a sub-

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discipline, had an easy birth and a successful adolescence, but as it matures it is experiencing problems with its image. Weed scientists grew up in a divorced household and conversation with their scientific parents is just beginning. Duke (1992, p. 184) has commented that "the lack of a strong continuum of expertise and cooperation between the basic and applied aspects of weed science has been a major factor in preventing weed science from gaining the stature of [other pest control disciplines]."

Agricultural scientists have been comfortable and secure with the mission of a land-grant system that had withdrawn into itself. They ignored the founding sciences, academic colleagues, and public criticism that they regarded as unreasonable (Danbom, 1992). But that system is being questioned now as never before (Browne et al., 1992). The land-grant model, whose basic value has been to produce, was appropriate at first (Meyer, 1993), but it is not as relevant as it once was.

Weed scientists, divorced from their founding disciplines, risk separation from the mainstream of their institutions' intellectual life or, as agriculture loses its special position in the academy, they risk entering the mainstream without the requisite navigational skills. Weed science is regarded as a stepchild by some of its most devoted adherents (Burnside, 1993). Therefore, either weed scientists must participate in shaping their future, or their mission and identity will be determined by others.

Weed Science and Herbicides

Some argue that weed science is not dominated by herbicides, and that reliance on them is not too great. Others argue that the history of weed science is similar to the well-known story of the drunk who lost his housekey in the dark near home but was searching for it under a streetlight because "the light is better here." Herbicides such as 2,4-D were a new technology that worked so well that most research was oriented toward elaborating that technology. The work was dynamic, rewarding, optimistic, and backed with administrative support (Dundon, 1982). There is nothing surprising about the tendency of any scientific community to exploit success. That is how progress is made. Weed scientists would have been negligent if they had ignored or quickly tired of the dramatic successes created by herbicides. Narrowing of attention frequently leads to progress (Dundon, 1982), and weed science progressed. However, one can criticize subsequent organizations and scientists that advocated and used herbicides without ever questioning their goals or the means of achieving them.

For the reasons mentioned above (Dundon, 1982), weed science concentrated "where the light was better" — on exploration and development of herbicides. Now, however, the important question is not what weed science has been doing, but what it should do and what it might become. Most weed scientists do not advocate abandoning herbicides that are effective, cheap, reliable, and safe to humans and the environment. Few unresolvable questions arise about the effectiveness or cost of herbicides, but there is serious debate about their reliability and safety. Many questions arise outside the weed science community that involve the most basic aspects of reliability and safety. Safe for whom? Reliable for how long? Who gets to decide, and what criteria will be used? Who is responsible? There are many who now believe that because of the widely recognized problems with chemical technology, the balance needs to be shifted away from herbicides. The light has improved in other places!

No doubt most weed scientists agree that weed control should avoid or eliminate techniques that have a high potential to harm others. Leopold (1949 [1970], p. 262) offered the fundamental ecological principle that "a thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise." Herbicides and other weed management techniques bend nature to human will, and in doing so may harm it, not preserve it. In Leopold's terms, they may tend to be wrong. Changing research emphasis away from herbicides requires informed debate about the criteria for reliability and safety of weed management techniques and about the direction weed science should take.

Integrated Weed Management Systems

The economic or profit orientation of agriculture led to the quest to maximize short-term yield, which often is not sustainable. The quest was created in large part by government policies that determine what farmers can do, and by grant programs that determine what research is done. For example, Browne et al. (1992) argue that price and income support programs contribute to environmental degradation by encouraging farmers to produce increasing amounts of particular crops. These policies encourage farmers to use more pesticides, farm fragile land, exploit aquifers, and not rotate crops. They also lead to research on methods of weed control that may contribute to environmental degradation.

Scientists must be aware of political and economic agendas but need not be directed exclusively by them. Weed scientists routinely discuss a variety of research ideas, but availability of research funds frequently restricts their ability to pursue some of them. For example, is the proper research goal maximum short-term yield, maximum sustainable yield, or maximum yield stability (defined as "maximum low-cost, low-flux, sustainable yield") (Jackson, 1984; Weiner, 1990)? What weed science techniques are required to achieve the chosen goal? Again: "How should farmers farm?" (Wojcik, 1989).

Weed science is moving toward integrated, sustainable weed management systems. To develop these systems, we must study the botany and ecology of weeds. Present technology, especially chemical technology, cannot be relied upon for all solutions. Many weed scientists are eager to learn what botany, population biology, and ecology can contribute to the development of weed management systems. These disciplines have not contributed much to weed management or modern agriculture because there has been little funding for joint research (Weiner, 1990) and because there is little scientific interaction among disciplines. Plant population biology and the design of agroecosystems are not a usual concern of weed scientists, who have not looked to them to solve weed problems (Weiner, 1990). Other disciplines, often critical of agricultural practice, have not been eager to understand and cooperatively solve the weed management problems they see.

Population Biology and Ecology

Changes in agricultural practice have largely ignored ecological concerns. Production problems were solved by adding fertilizer,

water, and pesticides (often excessively), or by reshaping the land itself (Woodwell, 1979), which created ecological problems. Cheap energy has been the panacea that made it possible to maximize yield and replace any natural plant community with one consisting of a few crops, and to do so profitably. In earlier times, things were dear and people were cheap (Woodwell, 1979) and sound ecological practices often were the way things were done. As technology advanced, things became cheap and people dear, and weed and other agricultural scientists neglected ecology, evolution, carrying capacity, limiting resources, and limits to growth. Technology reigned supreme, and weed scientists knew their technology was both socially beneficial (food production increased) and environmentally beneficial, or at least benign (there was no obvious harm). They were wrong, because technology is never neutral, and always induces social change. One should not blame the technology and perhaps not even its developers and users. Early weed scientists wanted to solve weed problems. When the magic of chemical technology appeared, they seized it to replace human and animal energy for weeding, and it worked well.

Weed scientists were reminded about limits by Rachel Carson (1962), whose book, I suspect, was dismissed by many who hadn't read it. Her profoundly moral statement tried to convince the reader that life is a miracle beyond comprehension and that we should revere it even when we have to struggle against nature. Chemical control of pests was part of Carson's permissible struggle, but she saw it as a misguided, nonecological attempt to control nature. Pesticides were not her first line of defense.

The key to sustainable management of annual weeds is prevention of seed production (Kremer, 1993). The life cycle of an annual weed includes seed germination, seedling survival, growth, flowering, seed production and shed, seed predation, and mortality. Kremer (1993) reviewed the effects of microorganisms on the viability of weed seeds and suggested that they be integrated with other seed management approaches. Weed science has focused on control of viable seedlings, with too little known about the rest of the life cycle. It is impossible to say how such biological knowledge will be integrated into new, sustainable management systems and reduce reliance on herbicides. Systems that suppress weeds will be developed when research on weed population dynamics and crop-weed interference is integrated with systematic manipulation of components of cropping systems to isolate and improve specific factors that affect weeds (Liebman and Dyck, 1993). The emerging literature on weed population biology and ecology will be the necessary foundation to create sustainable, integrated weed management systems that reduce herbicide use.

Ethics

Carson (1962) never proposed abandoning pesticides. Rather, she proposed accommodation between pests and people, with ethics the means to that end. Weed scientists need to develop an ethical base to support the need for weed management in sustainable agricultural production and the need for a protected environment. Weed scientists want to include ecological thinking and guidance in the quest for sustainable weed management systems that accommodate these equally valuable but divergent needs.

I suggest that the ethical base for weed science, its technology, and its systems must also include consideration of effects often deemed external, such as the disappearance of family farms, the decline of rural communities, reduced water quality, and effects on nontarget species. Weed science is part of agricultural science, and it will succeed or fail with all of agriculture. Agriculture is part of human culture and must function as part of a shared, sustainable system rather than striving for domination. Ethics are not the stuff of casual conversation. They are often relegated to the realm of private anxiety, as if it would be awkward or embarrassing to make them public (Bellah et al., 1985, p. vi). Ethical discussions do not usually deal with solid, data-laden, objective things, but rather with amorphous, nonquantitative things. There are good, universal values—things that are right—such as compassion, honesty, fairness, and accountability. Each expresses caring, and I suggest weed science should develop an ethical stance that reflects equivalent care for a productive and protected environment.

The careers of many of today's weed scientists developed while the agricultural research system was moving from being a "revered institution, as little questioned as apple pie or motherhood, to an embattled giant assailed by enemies from without and undermined by critics within" (Danbom, 1992, p. 102). We are witnessing, if we look, the unraveling of the social consensus that progress is always good and science is always beneficial (Danbom, 1992).

A frequent response to critics of the benefits of herbicides and chemically based weed science has been an appeal to the neutrality of objective scientific knowledge. A common theme is that if the public were aware of the extensive safety testing that herbicides must undergo, and if they understood scientific research, they would recognize that herbicides are both needed and safe (Doering, 1992). This response is based on what Shader-Frechette (1991) calls the realism argument. The rationale is that "although chemical pest control is hazardous, it is realistic to accept the minimal degree of risk it presents, since absolute safety is unattainable in any sector of life" (p. 427). The argument recognizes that risks and benefits must be balanced, while incorrectly assuming that the acceptability of any pesticide is only a matter of the magnitude of the risk or physical danger. It ignores risk distribution and the involuntary nature of many risks (Shader-Frechette, 1991).

The realism response can be regarded as a defense of the status quo. Many critics of herbicides are competent, intelligent scientists who espouse a different risk preference. They will immediately dismiss a defense of herbicides based on the unquestioned correctness of science. Although science deals with facts and objective truths, scientists cannot stop with that defense. The public perceives that once scientists have the objective facts, they assume that nothing else is required, no other listening is needed. "The facts, after all, are the facts. All that remains is to bring others into conformity with objective truth" (Palmer, 1993, p. 68).

A response that reflects a desire to cooperatively understand (to listen) would be better. Weed scientists value, promote, and defend their role in production but have not listened carefully or responded well to the social and ethical arguments central to environmental protection (Doering, 1992).

Future Questions and Thoughts

Weed scientists have developed ways to control weeds and will continue to do so.

Many weed scientists now believe weed "control" should not dominate, and alternative weed "management" methods are being widely discussed. Within weed science it is unusual to ask if agriculture can be successful without controlling weeds (Soule et al., 1990). Can farmers work *with* weeds rather than *against* them? The evidence (not presented here) from studies of crop rotation and intercropping (Liebman and Dyck, 1993), living mulches, cover crops, tillage systems (Mohler, 1993), and allelopathy suggests the answer is yes for many cropping systems. Pursuing the practice of agriculture by managing rather than controlling weeds would shift weed science's emphasis toward economical, environmentally sound, integrated, sustainable weed management systems.

Some argue that weed science cannot continue to insist on fighting to the last weed, but many weed scientists and farmers disagree. Some are questioning the goal of 100% control, a goal that herbicides have made possible for most cropping systems. However, most crop scientists acknowledge that the need for weed management will never end. Weeds will always be with us, but weed scientists and farmers should not work against them but with them (Jackson, 1984; Doering, 1992). Weeds won't just be controlled, they will be managed.

Weed science, with its emphasis on control, has been very successful—most weeds can be controlled in most places. There is much about weed science that must be lauded: weed scientists' achievements in basic science (Duke, 1992) and their contributions to agricultural production and productivity worldwide are incontestable. However, the discipline has not been integrated into a holistic view of agriculture and our world, and it lacks a sustainable ethical base. Weed science has worked with a spotlight, not a floodlight. The work has not been illuminated much by associated disciplines, nor has it enlightened them, and the contribution to agriculture has been constrained by intensive specialization and narrow expertise. Mayer and Mayer (1974, p. 87) accused agriculture of being "intellectually and institutionally . . . a vast, wealthy, powerful . . . island empire." Weed scientists are residents of a technologically rich domain in that empire.

The public is well aware that technological problems multiply and that remedies may not exist. Technology is often perceived as something that brings vast resources to solve problems, lots of experts and new policies, but few solutions for the problems it creates. Weed science is identified, rightly or wrongly, as a discipline based on chemical technology. When the tools and techniques of chemical technology were chosen, dreams and values also were chosen. Weed scientists need to discuss whether the dominant technology has served their dreams and helped them create appropriate, enduring values, or if it has made some of them unobtainable. The public image created by dependence on herbicides is a concern to many and a source of frustration and discouragement to others. Because of the public's image of pesticides, the entire pest control community often feels under siege. Too often the news includes an example of another pesticide problem that affects everyone involved in pest management. For example, recent Roper Reports (1989-1992) reveal that 86% of Americans think that pesticide residues on food are a serious issue, 84% are concerned about health hazards of pesticides to farmers and other users, 86% believe that water pollution from chemical runoff is a serious environmental issue, 84% cite pesticide use on farms as an environmental concern, and 62% think chemical soil contamination is a serious problem.

Weed scientists are almost defenseless against accusations about herbicide reliability or safety when so many people are concerned. If the validity of the concern is denied, those who deny it risk becoming identified as advocates of potentially dangerous chemical technology. If the implications of the concern are affirmed, people wonder why practices don't change and why herbicide use doesn't decrease. Scientists may be accused of not understanding where agriculture must go, being poor environmental stewards, and being insufficiently accountable for their science and its technology or accountable to the wrong sectors of society.

Weed scientists frequently respond with arguments that emphasize the importance of productivity, and they object when they think that politics rather than science is determining what happens. There will inevitably be political decisions that take place in the midst of a philosophical reassessment that is coupled with ecological and moral concerns about how humans should value nature and what techniques should be used to produce food and fiber. These are not simply scientific matters. They are inherently "political decisions entwined with reforming world views" (Rolston, 1990, p. 21).

Modern, objective, reductionist weed science has the ability to look inward and change. Weed scientists are part of a belief community shaped by its members, their purposes, and the available technology. Their justifiable pride in scientific objectivity and rationality should be tempered to include and validate the subjective role of each scientist as it is informed by the community and its commitments. Knowledge is neither solely subjective nor solely objective.

Weed scientists should begin to tell the public and themselves that the quality of the American food supply, not just the quantity, is a high priority. A protected environment is as important as a productive environment. Weed scientists may not know all the changes needed in their community, but they know enough to get started. Some criticism of weed science is unfair and ill-informed, but that is not new. Most people don't understand agriculture or weed science.

As weed scientists make changes in their goals and methods, they would do well to heed Kennedy's (1993) advice for the future. Speaking about education, he said that what is needed is "a deep understanding of why our world is changing, of how other people and cultures feel about those changes, of what we all have in common — as well as of what divides cultures, classes, and nations. The process of inquiry ought if possible to be tolerant, . . . but it cannot be value-free. . . . Because we are all members of a world citizenry, we also need to equip ourselves with a system of ethics, a sense of fairness, and a sense of proportion as we consider the various ways, collectively or individually, we can better prepare for the twenty-first century" (Kennedy, 1993, p. 341).

The work weed scientists are most proud of is often not the work the public understands easily or appreciates. Most people do not know what weed scientists do. They are confused by obtuse scientific jargon, are increasingly uncertain about who is right about the technology of weed science, and often view scientists with suspicion and distrust. Predictably, they react by accepting

whatever view fits common sense and their biases. This reaction, while personally rational, is often regarded by weed scientists as illogical and emotional. It frustrates thought and wisdom, but does not preclude them. Weed scientists, like most people, are wary of change, especially when imposed. The science is changing, but some changes may be perceived by others as an alteration only of form, not content. Weed scientists have always claimed that no weed control technique has ever been abandoned, but it must be asked if new weed management methods can be developed from old ways. New methods may rely on new knowledge derived from different questions about weed-crop relationships. To find a better medium, weed scientists may have to find a different message.

Weed scientists must begin to debate their message and their medium as they establish an ethical foundation for the science. Through public presentation and debate, ideas will be tested and refined so that weed science will continue to contribute to agriculture and society.

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Diazinon May Be "Impoverishing" Central Valley's Aquatic Life

The pesticide diazinon "may be impoverishing the [California] Central Valley's aquatic web of life," according to an article in the *Sacramento Bee* (June 17, 1995). Water samples taken by the Central Valley Regional Water Quality Control Board, which contained diazinon residues, consistently killed tiny water fleas which serve as food for fish in the region. "Some scientists speculate that diazinon and chlorpyrifos, another popular pesticide found in samples, may contribute to a problem that has plagued the Delta and San Francisco Bay in recent years: poor production of the tiny animals that feed countless bigger animals, including Delta smelt, striped bass, and salmon," according to the article.

In 1993, farmers, homeowners, gardeners, and professional pest control operators in California bought 2 million pounds of diazinon and 2.4 million pounds of chlorpyrifos. Farmers spray diazinon in the winter to protect fruit and nut tree buds, and homeowners apply the liquid and granual poisons to kill a variety of insects. "Pesticides were never meant to be washed down storm drains, tubs and sinks," district source control superintendent Barton Brandenburg told the newspaper. "We're not killing fish directly, but if we kill the food source, we're indirectly impacting fish."

BOOK REVIEWS

Sustainable Agriculture in the American Midwest. Edited by Gregory McIsaac and William R. Edwards. 1994. University of Illinois Press, Champaign, IL 61820. 291 pp. $32.95, hardcover.

This book is a collection of ten chapters presenting various economic, ecological and social perspectives on midwestern agriculture, sandwiched between introductory and synthesis chapters that deal with the broader conceptual issues of agricultural sustainability. Individual parts of the book, including the introductory and synthesis sections, provide informative and worthwhile reading. However, the book as a whole does not convey many new insights into the sustainability of agriculture in the American Midwest.

Each chapter relates to an important dimension of agricultural sustainability, but there was no apparent attempt to provide a balanced treatment of economic, social and ecological issues. For example, the only chapter written by an economist presents a very narrow treatment of agriculture and forestry as sources of renewable energy. Nor do the authors of individual chapters make more than passing mention of how their chapters are connected to the others. On the other hand, several authors touch on issues related to economic policy, but there is no chapter that lays the conceptual foundation needed for these policy discussions. The ecologic, economic and social dimensions of sustainability cannot simply be developed as separate components and afterwards woven into a meaningful whole. The authors may understand the holistic nature of sustainability, but this principle is not conveyed to the reader.

Gregory McIsaac's introductory chapter on the conceptual evolution of sustainable agriculture is an excellent resource for understanding sustainable agriculture as both a public issue and a paradigm for farming in the future. His discussion of sustainability and sustainable agriculture is informed, balanced and insightful. In Chapter 2, on indigenous agricultural knowledge, Dennis Michael Warren provides a fascinating historical sketch of midwestern agriculture from Native American systems to today's conventional capital-intensive systems, giving specific attention to the value of knowledge of local agroecosystems. Sonya Salamon's chapter on ethnicity and cultural beliefs takes an anthropological case study approach to understanding the impacts of cultural heritage on today's farming methods. She uses two communities, one German and one English, to link cultural differences to differences in current farming paradigms.

In Chapter 4, on land drainage and conflict resolution, John Thompson provides an interesting historical sketch of how the wetlands of the Lower Valley of the Illinois river were converted into productive farmland. He provides valuable insights into the current controversy surrounding both conversion and reclamation of wetlands throughout the Midwest. This is followed by a chapter on agriculture and wildlife by William Edwards, which also is largely historical but useful in understanding current issues related to preservation of habitat for wildlife on midwestern farms.

Chapter 6, on natural ecosystems, takes the reader in a different direction. Authors Bruce Hannon, Matthias Ruth and Evan DeLucia discuss the thermodynamics of ecosystem sustainability, in particular the maximum capture of solar energy, using the natural ecosystem as a standard. While providing an interesting intellectual exercise, this approach seems to treat the human species as an intruder upon nature rather than an integral part of nature. James Power's chapter on cropping systems effectively addresses an important component of sustainable agriculture, but within a total systems context, and is probably the best chapter in the book. Richard Weinzierl's chapter on pest management is similar to it, but is more narrowly focused on pests, and provides few new insights into the role of integrated pest management in sustaining agriculture as a whole. Chapter 9, by Kenneth Olson, is even more narrowly focused, covering the formation, use, and misuse of soils. It treats these as largely separate from any economic, cultural or social considerations. The two remaining chapters on specific topics, respectively on paleoclimates (Wayne Wendland) and energy farming (Folke Dovring), are interesting, but seem more like add-ons, with no special linkage to the other chapters.

In the final synthesis chapter, McIsaac begins with an attempt to link the other chapters in the book to the broader issues of sustainable agriculture, but soon turns in a more fruitful direction, supporting more comprehensive approaches to achieving sustainability. The concluding section of this chapter is worth careful study, suggesting thoughtful directions for discussions of strategies to achieve agricultural sustainability.

The most significant contribution of this book to the sustainable agriculture literature may be the historical information provided in many of the chapters. The key to answering the questions of agricultural sustainability may lie in a better understanding of the historical roots of our current doubts about whether conventional agriculture is sustainable in the long run.

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Agricultural Ethics: Issues for the 21st Century. Edited by Peter G. Hartel, Kathryn Paxton George, and James Vorst. 1994. ASA Spec. Pub. No. 57. Soil Science Society of America, American Society of Agronomy, and Crop Science Society of America, 677 South Segoe Road, Madison, WI 54711-1086. 70pp. $21.00, paper.

These seven essays clearly show why everyone concerned with agriculture's future needs to learn how to explore ethical questions. In the opening article, Peter Hartel, a soil microbiologist who coordinates the Environmental Ethics Certificate Program at the University of Georgia, points to three now-unavoidable issues that cannot be resolved without discussing ethical values: the treatment of animals in agriculture, the debate between conventional and alternative agriculturalists, and the spread of world

hunger. Hartel also frames the articles that follow by pointing to the necessity of going beyond discussion of efficiency and usefulness to deeper values that cannot be priced, such as community, intergenerational equity, and human or animal welfare.

Each author then proposes ways to think about ethical questions within a larger framework of ideas about the ultimate values or goals of agriculture and society. For example, philosopher Frederick Ferre, also of the University of Georgia, adds to Hartel's comments by drawing out the evidence that justice is an ethical value that cannot be ignored if sustainability is to be achieved. "Without doing right, we cannot long maintain the good," he asserts. Philosopher Charles Blatz, of the University of Toledo, discussing the ethical dilemma that seems to confront agriculturalists, puts it this way: "How can we choose between the productivity needed to feed the world today and the sustainability needed to feed the world tomorrow?" As an answer, he proposes that both traditional and industrialized agriculture adjust their practices as they reach for the three goals that he thinks should guide agriculture: personal, cultural, and moral sustenance. The reflection is taken a step deeper by theologian Dean Freudenberger, of Luther Northwestern Theological Seminary, who suggests that the expression of gratitude for our opportunity to participate in life is what makes us human, and that taking responsibility for the future is one way of showing that gratitude.

Soil scientist Thomas Ruehr, who with Stan Dundon at California Polytechnic State University developed one of the first courses on agricultural ethics, closes the volume by arguing that we learn how to do ethics precisely by entering into the discussion of values. "To become effective in decision-making, we need to identify what values we hold and understand why we cherish them," he writes. In all, this text is valuable precisely as an introduction to the process of clarifying values that Ruehr suggests we all undertake. It makes the value questions clear and understandable without undue academic jargon, and it gives us as examples the seven voices in the 1992 symposium at which these essays were first presented.

The usual question that arises after hearing diverse perspectives is what the commonalities and differences imply. If these articles typify ethical discussion among agricultural professionals, the collection suggests that a consensus is emerging regarding the importance of long-term sustainability for healthy human societies, and that this goal implies that care for other species and the land must be part of achieving sustainability. Where positions are clearly stated, the differences that emerge here are more a matter of diversity of language and degrees of concern than radical differences in perspective about such matters as animal welfare. None of the authors defends the value of maximum profit or production at any cost to the land or to animals, for example. This raises the question of whether the very process of ethical reflection rules out maximizing profit as a singular goal (money, as those who have studied ethics know, is usually considered a means to another end). Perhaps no advocate of "production at any cost" could be lured into an ethical discussion. If so, this is interesting in itself, since it suggests that moving to ethical discussion will inevitably raise questions that tilt in favor of long-term sustainability in human affairs, including agriculture. Less understandable is the absence of a radical voice for elimination of animal agriculture, as is the absence of a clear response to the issues raised when one seeks both sustainability and elimination of world hunger.

Overall, however, the volume makes its key point: that we cannot ignore agricultural ethics. The global changes we are experiencing, affecting both the earth and human society, are so great that we all must become more conscious of our fundamental values and learn how to clarify and debate them in public forums. Alternative agriculturalists who for many years have embraced the goals of sustainability and concern for community and "priceless" values will be encouraged that the three major professional agricultural societies who published this volume clearly support the pursuit of this discussion.

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Clean Water Bill Would Eliminate Controls on Factory Farms, Says NRDC

A Clean Water Act bill passed by the U.S. House of Representatives (H.R. 961) "could effectively eliminate Clean Water Act controls on factory farms," according to a new report by the Natural Resources Defense Council (NRDC). The bill "could mean more toxic animal waste spills like the huge hog waste spill [in June] in North Carolina," NRDC said, referring to the 25-million-gallons of hog waste that spilled out of the Oceanview hog farm's lagoon, killed an estimated 4,000 fish, closed a nearby river to swimmers and boaters, and threatened shellfish beds 15 miles downstream.

According to NRDC, the Clean Water proposal in Congress would not require factory farms to determine whether the manure they dumped was harmful, to get a permit from the Corps of Engineers before building a waste lagoon in a wetland, or to be held accountable for any discharge of manure waste into U.S. waters. The bill also removes whole categories of the factory farm industry from the definition of "Confined Animal Feeding Operations," thus removing them from permit requirements and controls.

"Hog Wash: Factory Farm Giveaways in Clean Water Proposals," is available for $5 plus $1.45 shipping from NRDC Publications Department, 40 West 20th St., New York, N.Y. 10011.

Guide for authors

The American Journal of Alternative Agriculture (AJAA) publishes original research on biological, physical, or social science aspects of alternative agriculture. We particularly welcome multi-disciplinary studies, but papers from a specific discipline also are invited. However, since AJAA readership is much broader than for a single-discipline journal, highly specialized terminology should be explained or avoided. The significance of a statement, or the reasoning behind a conclusion, may have to be spelled out more than in a more specialized journal. See Vol. 5, No. 1, pp 2 & 3, for an explanation of the various categories of articles.

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